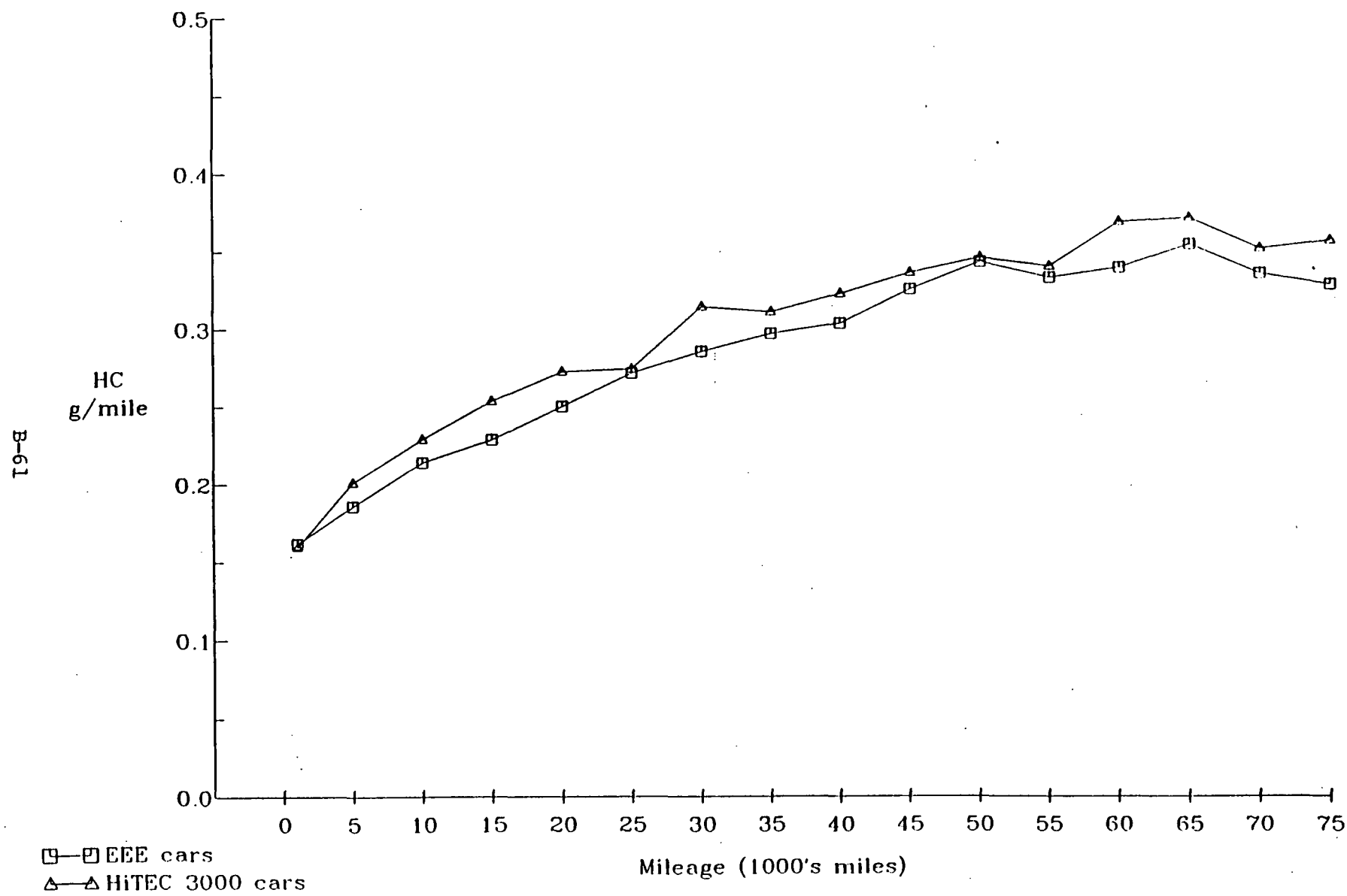
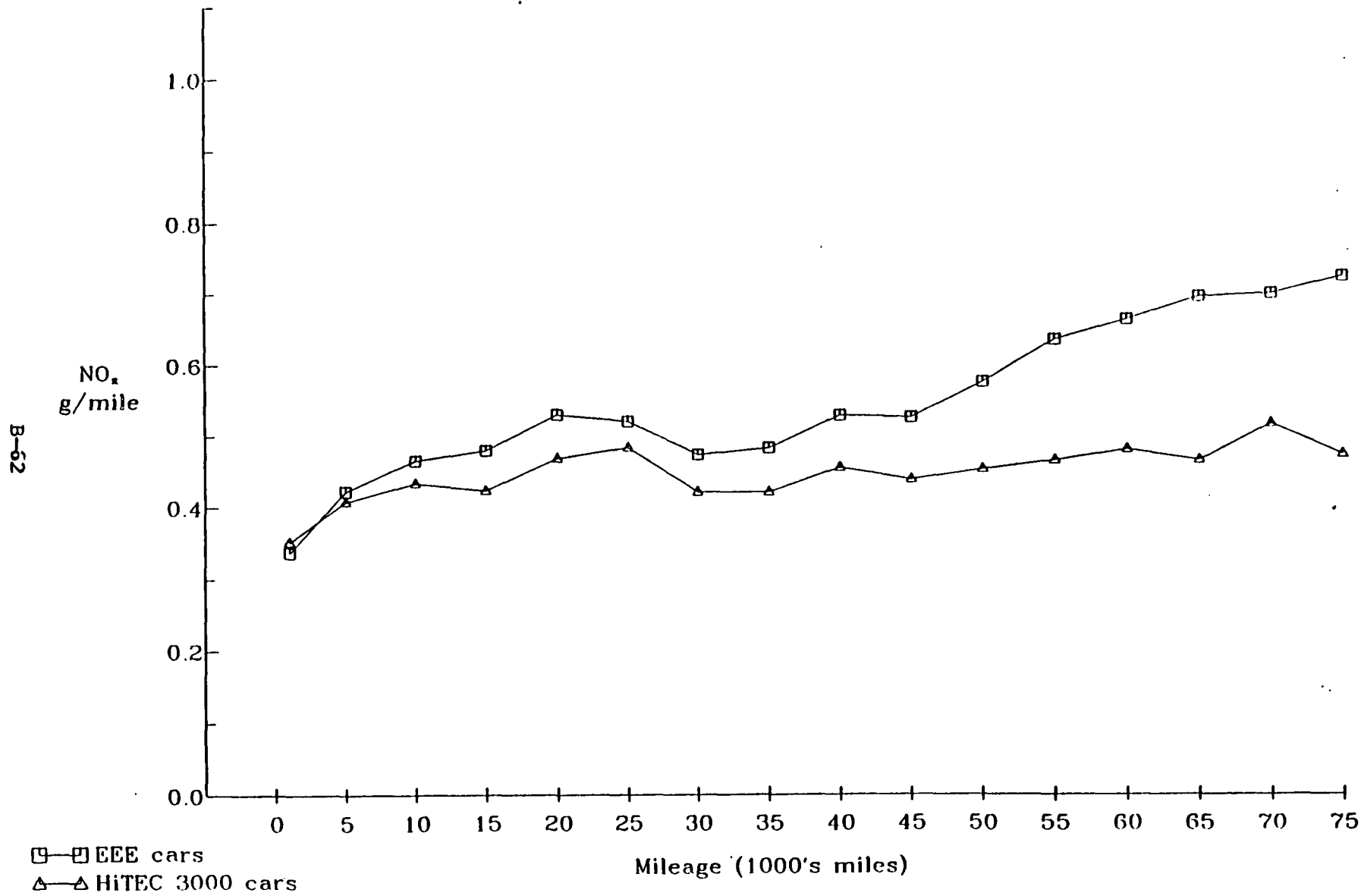


Weighted Average Tailpipe Hydrocarbon Emissions



Weighted Average Tailpipe Nitrogen Oxides Emissions

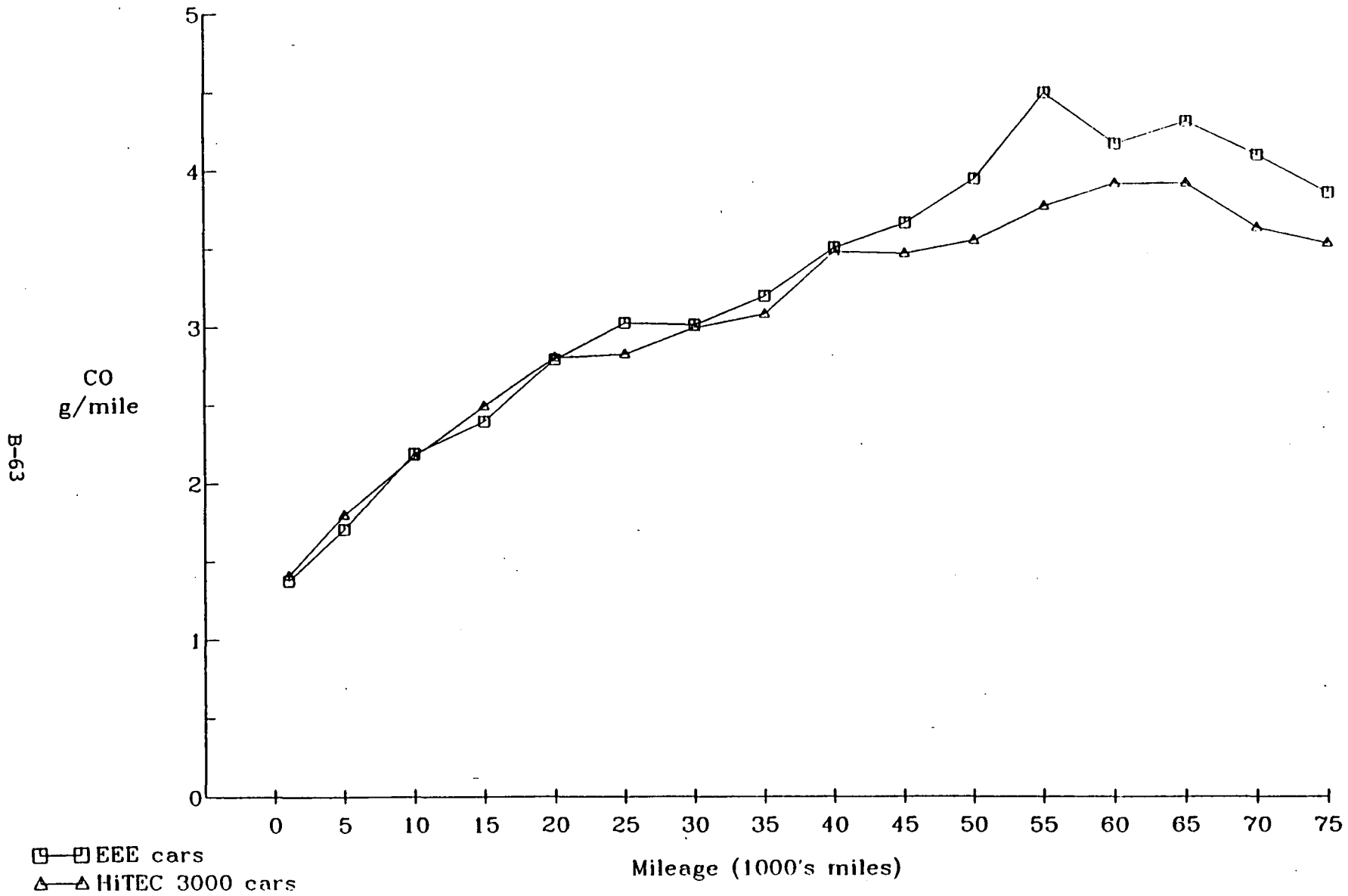


ETHYL4S2 4/16/90

Systems Applications, Inc.



Weighted Average Tailpipe Carbon Monoxide Emissions



Appendix 2B



ROBERSON PTTTS, INC.

ANALYSIS OF ETHYL EMISSION TEST DATA

April 1990

Prepared for
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Report No. 90-220-06FD

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1. INTRODUCTION

1.1 BACKGROUND

Ethyl Corporation is filing this waiver application pursuant to Section 211(f)(4) of the Clean Air Act to demonstrate that the HiTEC® 3000 fuel additive ("HiTEC 3000") does not cause or contribute to the failure of emission control systems to meet applicable automobile emission standards. Ethyl Corporation has conducted an extensive automobile emission testing program in order to obtain the data necessary to support the waiver application.

1.2 PURPOSE, SCOPE, AND LIMITATIONS

Ethyl Petroleum Additives, Inc. (EPAI) retained Roberson Pitts, Inc. (RPI) to secure the services of David A. Dickey, Associate Professor of Statistics at North Carolina State University, to conduct statistical analyses of the emission test data. Dr. Dickey was directed to apply best available statistical techniques to determine (1) how HiTEC 3000 affects hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NO_x) emissions and (2) if HiTEC 3000 causes or contributes to the failure of emission control systems to meet applicable emission standards.

EPAI also retained Systems Applications, Inc. (SAI) to conduct an independent analysis of the emission data and to assess ambient air quality impacts associated with the use of HiTEC 3000. While SAI and RPI conducted their analyses independently, RPI received the raw data from SAI. This procedure eliminated some duplicative efforts (e.g., inputting and verifying the raw data) and ensured that both firms were analyzing the same data.

RPI's results for 50,000-mile and 75,000-mile emission test data are based on an analysis of Data Set 4 (designated by SAI as ETHYL4S2). Data Set 4 is a subset of Data Sets 1, 2, and 3. Data Set 4 does not include emission data that (1) were invalidated based on an engineering analysis; (2) were obtained just prior to unscheduled maintenance; (3) were obtained in addition to that required by the original experimental protocol; and (4) were obtained for car D-3 after it was wrecked. Additional discussion of how the data subsets were created is provided in SAI's report. All of RPI's analyses are based on average values for HC, CO, and NO_x for each car at each mileage interval. That is, RPI used the average value of replicate (usually two but sometimes four) measurements conducted at each mileage interval for each car. All emission data and analytical results are reported in the units of grams per vehicle mile (gpvm). Statistical analyses presented in this report are based on application of SAS® procedures*. All results based on analysis of 50,000-mile emission test data are contained in Section 2 of this report. All results based on analysis of the 75,000-mile data are presented in Section 3 of this report.

1.3 SUMMARY AND CONCLUSIONS

1.3.1 T-Tests

To assess initially the effect of fuel type on emissions, we conducted a t-test for each car model at each mileage interval. For the 50,000-mile data,

* SAS® is the registered trademark of SAS Institute Inc., Cary, North Carolina. SAS® is a software system that provides data retrieval and management, programming, statistical, and reporting capabilities.

there were 88 t-tests (8 car models x 11 mileage intervals) for each of the three pollutants. If there were no true difference between clear fuel and HiTEC 3000, natural variability in sampling would lead us to expect (at the 95 percent probability limit) about five cases in each of the two categories. That is, we would expect about five cases where HiTEC 3000 emissions are higher than clear fuel and about five cases where HiTEC 3000 emissions are lower than clear fuel.

For the 75,000 mile-data, there were 128 t-tests (8 car models x 16 mileage intervals) for each of the three pollutants. If there were no difference between the two fuels, sampling variability would lead us to expect about seven (i.e., $0.05 \times 128 \approx 7$) cases in each of the two categories. We have enumerated and tabulated the number of statistically significant t-tests in Table 1-1. Since Table 1-1 compares HiTEC 3000 to clear fuel, "higher" means that HiTEC 3000 emissions are higher than clear fuel. Likewise, "lower" means that HiTEC 3000 emissions are lower than clear fuel.

TABLE 1-1. NUMBER OF STATISTICALLY SIGNIFICANT T-TESTS --
HiTEC 3000 VERSUS CLEAR FUEL.

Pollutant	1-50,000 Miles	1-75,000 Miles
HC	25 Higher; 1 Lower	32 Higher; 1 Lower
CO	8 Higher; 12 Lower	9 Higher; 21 Lower
NO _x	3 Higher; 22 Lower	3 Higher; 41 Lower

We observe that t-tests use a very small amount of the total available data and thus have relatively little power to detect differences. However, it is interesting to compare the 50,000-mile t-tests with the 75,000-mile t-tests.

We see that most of the statistically significant HC increases occur prior to 50,000 miles. On the other hand, the number of statistically significant results for CO and NO_x increase with increasing mileage, and there are considerably more cases with lower emissions due to HiTEC 3000.

1.3.2 Statistical Models

For our next analysis we fit statistical models to the data to account for the effects of car model and fuel type. The statistical models pool all of the data from all of the cars at each mileage interval. Application of this model allows us to obtain an overall comparison of HiTEC 3000 versus clear fuel emissions by mileage interval. Note that these statistical models do not allow fuel effects to be model specific. Results of this analysis are described in the following paragraph.

For HC emissions, clear fuel results in slightly lower emissions than HiTEC 3000 at every mileage interval. However, the differences in HC emissions are not statistically significant at 1,000 miles nor from 45,000 to 75,000 miles. This suggests: (1) there was no true difference in HC emissions between the two fleet of cars when the HiTEC 3000 versus clear fuel tests began and (2) HC emissions from HiTEC 3000-fueled cars initially increased faster than those with clear fuel, but this trend changed, and by 45,000 miles there was no true difference in HC emissions. We repeated the analysis for CO emissions and found statistically significant differences at 45,000 and 50,000, 55,000, 60,000, and 70,000 miles -- with HiTEC 3000-fueled cars having lower CO emissions than those with clear fuel. The results of this analysis for NO_x emissions indicate that from 30,000 miles and beyond, clear fuel results in

statistically higher emissions than does HiTEC 3000. Moreover, the magnitude of the differences in NO_x emissions increases with increasing mileage.

1.3.3 Analysis of Quadratic Functions

Lastly, we report on the analysis that we believe most clearly depicts the results of the emission testing program. We refer to this as an analysis of quadratic functions because it is based on fitting quadratic equations to the emission data for each individual car and for each of the three pollutants. Once we determine a quadratic function that describes the emissions of a pollutant for an individual car as a function of mileage, there are several analyses that can be performed. First, for the 50,000-mile data, we computed average emissions and differences in average emissions for HiTEC 3000 and clear fuel cars. We computed these averages by integrating each function between 1,000 miles and 50,000 miles and then dividing by the mileage interval (i.e., 49,000 miles).

Then, using the 75,000-mile data, we refit quadratic equations to the emission data for each individual car and for each of the three pollutants. Average emissions and differences in average emissions for HiTEC 3000 and clear fuel were computed by integrating each function between 1,000 miles and 75,000 miles and dividing by the 74,000-mile interval. The results are summarized in Table 1-2.

TABLE 1-2. AVERAGE DIFFERENCES IN EMISSIONS (gpvm) --
HiTEC 3000 VERSUS CLEAR FUEL.

Pollutant	1-50,000 Miles	1-75,000 Miles
HC	0.023 Higher	0.020 Higher
CO	0.003 Lower	0.139 Lower
NO _x	0.059 Lower	0.097 Lower

Because HC emissions are slightly higher with HiTEC 3000 and because certain cars exceed the HC federal emission standard of 0.41 gpvm for both clear and HiTEC 3000 fuels in the first 50,000 miles of vehicle operation, we designed an analysis to determine if HiTEC 3000 contributed to the failure. Using the individual quadratic functions, we estimated the mileage at which each car is predicted to exceed the emission standard. We found that all D, F, and T model cars (both clear and HiTEC 3000) are predicted to exceed the HC standard within (or very shortly after) the 1,000 to 50,000 mile interval. Our analysis of exceedance mileages shows, however, that there is no statistically significant differences in exceedance mileages between HiTEC 3000 and clear fuel. That is, the variability in exceedance mileages renders the exceedance mileages for the two fuels indistinguishable. This, in turn, suggests that HiTEC 3000 does not cause or contribute to the failure of car Models D, F, and T to achieve the HC emission standard. Obviously, HiTEC 3000 does not cause or contribute to the failure of car Models C, E, G, H, and I to achieve the HC emission standard because none of these individual cars failed to achieve the standard.

With respect to CO emissions, all individual cars within Models D, E, H, and T (both clear and HiTEC 3000) exceed the CO emission standard within the 1,000

to 50,000 mile interval. A statistical representation that did not allow fuel effects to be car-model specific (i.e., that did not account for interaction between fuel type and car model) suggested a strong effect of car model but showed no statistically significant difference between clear fuel and HiTEC 3000. However, a statistical representation that allows for interaction demonstrated that there are car-specific effects.

Specifically, this representation predicted that Model E cars with clear fuel exceed the CO standard approximately 9,200 miles after HiTEC 3000 cars exceed the standard. On the other hand, the statistical model predicted that Model H cars with clear fuel exceed the CO standard approximately 8,800 miles before HiTEC 3000 cars exceed the standard. While both of these results are statistically significant, we conclude that these fuel effects on CO emissions tend to negate one another. This conclusion is substantiated by our statistical representation that did not allow for fuel effects to be car-model specific. This representation showed no statistically significant difference in exceedance mileage between clear fuel and HiTEC 3000.

No individual cars or car models burning HiTEC 3000 failed to achieve the NO_x emission standard in the 1,000 to 50,000 mile interval. Accordingly, we conclude that HiTEC 3000 does not cause or contribute to the failure of any car to achieve the NO_x emission standard.

Our analysis of exceedance mileage for the 75,000-mile data was not as straightforward as for the 50,000-mile data. For the HC analysis, one of the clear-fuel Model H cars is not predicted to exceed the emission standard within the 75,000-mile interval, but the other five Model H cars are predicted

to exceed the standard. Like the 50,000-mile analysis, all D, F, and T model cars (both clear and HiTEC 3000) are predicted to exceed the HC standard. However, without an exceedance mileage for the one Model H car, an analysis of variance on exceedance mileage is not technically supportable.

We encountered a similar problem with the exceedance analysis for NO_x. In this case, five Model F cars (three clear fuel and two HiTEC 3000) are predicted to exceed the emission standard within the 75,000-mile interval. That a particular car within a model group is not predicted to exceed an emission standard within a specified mileage interval is an important observation. However, without an exceedance mileage for the one Model F car, an analysis of variance on exceedance mileage is not technically supportable. Fortunately, our analysis of exceedance mileage for CO turned out to be the same as for the 50,000-mile data. That is, all individual cars within Model D, E, H, and T exceed the CO standard, and since all exceedances occur prior to 50,000 miles, the conclusions are the same as reported for the 50,000-mile analysis.

2. ANALYSIS OF 50,000-MILE DATA

2.1 SIMPLE STATISTICS

To assess the effect of fuel type on emissions, we initially conducted a t-test for each model at each mileage interval. There are 88 t-tests (8 models x 11 mileage intervals) for each of the three pollutants. The reader should recognize that when we pose the question regarding emission differences between HiTEC 3000 and clear fuel, we are actually asking about average emissions for two large groups of cars. In statistical terms, these large groups of cars are the "populations" (i.e., all those cars that will be driven on clear fuel and HiTEC 3000 in the next few years). However, we have to answer the question based on a few selected cars constituting a sample from the two larger groups. In order to provide what is called "statistically significant evidence of a difference in the population means", we must show that our two sample means differ by more than that which can be attributed to sampling variability.

The t-test quantifies this concept by taking the difference of two sample means and dividing it by the standard error. The standard error measures the variability we would expect to observe in the differences of two sample means if we repeatedly drew samples from our populations. The quotient (i.e., difference in means divided by standard error) is called the "t-ratio" and is a measure of how many standard errors away from zero our difference in means is. Statistical theory is used to compute the probability (i.e., P-value) of a t-ratio exceeding any given value when sampling from two normal populations that actually do not differ in means. Traditionally, a t-ratio that has less

than a 5 percent chance (i.e., $P\text{-value} \leq 0.05$) of being observed under the equal population means scenario is taken as statistically sufficient (significant) evidence to reject the null hypothesis (i.e., that there is no difference in the means of the two populations). We present the results of our t-tests in Tables 2-1A, 2-1B, and 2-1C for those cars where emissions are statistically different between HiTEC 3000 and clear fuel.

Referring to Table 2-1A, we see that there are 25 cases where HiTEC 3000 results in statistically significant, higher HC emissions than does clear fuel, and one case where clear fuel results in higher HC emissions. If there were no differences between the two fuels, sampling variability would lead us to expect about five cases ($0.05 \times 88 = 4.4$) in each of the two categories. Thus, HiTEC 3000 appears to result in slightly higher HC emissions than clear fuel, and this effect also appears to be a function of the car model being examined. That is, four car models (C, E, G, and T) account for 21 of the 25 t-tests where HiTEC 3000 results in statistically significant, higher HC emissions.

Referring to Table 2-1B, we see that there are eight cases (out of 88 t-tests) where HiTEC 3000 results in significantly higher CO emissions than does clear fuel; however, there are 12 cases where clear fuel results in higher CO emissions. Again, if there were no fuel effect on emissions, sampling variability would lead us to expect about five cases in each of the two categories. HiTEC 3000 appears to yield significantly lower CO emissions than clear fuel in Model F cars, sometimes in Model H cars, and in later mileage intervals in Model E cars. HiTEC 3000 appears to yield statistically significant, higher CO emissions than clear fuel in early mileage intervals

TABLE 2-1A. T-TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES IN HC EMISSIONS.

T-Test Number	Car Model	Mileage Interval	Mean Emissions (gpvm)		T-Test [Clear-HiTEC 3000]	P-Value
			Clear	HiTEC 3000		
1	C	15	0.15750	0.20400	-3.2088	0.01631
2	C	20	0.18950	0.23933	-7.0825	0.00105
3	C	25	0.17900	0.21400	-3.3627	0.01412
4	C	30	0.17492	0.21997	-3.3485	0.01430
5	C	40	0.17517	0.23900	-3.7623	0.00987
6	D	20	0.44100	0.51917	-2.9177	0.03080
7	E	5	0.13067	0.16100	-4.6893	0.00469
8	E	10	0.15450	0.18067	-2.8030	0.02433
9	E	15	0.14767	0.19000	-2.9820	0.02033
10	E	20	0.15567	0.20217	-3.6073	0.01131
11	E	30	0.17108	0.19483	-2.4518	0.03515
12	F	20	0.39900	0.42183	-2.7618	0.02538
13	G	15	0.10550	0.14150	-5.4170	0.00281
14	G	20	0.13550	0.17150	-3.9675	0.00829
15	G	25	0.14033	0.17333	-2.5460	0.03179
16	G	35	0.13550	0.18183	-3.2254	0.01606
17	G	40	0.13917	0.18217	-2.2721	0.04276
18	G	45	0.13767	0.17067	-2.1752	0.04763
19	H	35	0.32083	0.27450	2.6704	0.97211
20	I	40	0.17583	0.19417	-2.1730	0.04775
21	I	45	0.17783	0.20250	-2.5196	0.03269
22	T	10	0.24450	0.29717	-10.5799	0.00023
23	T	20	0.27967	0.32833	-2.2226	0.04518
24	T	25	0.30483	0.34600	-2.4147	0.03659
25	T	30	0.30175	0.37175	-3.2845	0.01519
26	T	35	0.33500	0.39800	-3.0037	0.01990

TABLE 2-1B. T-TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES IN CO EMISSIONS.

T-Test Number	Car Model	Mileage Interval	Mean Emissions (gpvm)		T-Test [Clear-HiTEC 3000]	P-Value
			Clear	HiTEC 3000		
1	E	5	2.65517	3.48400	-4.1926	0.00689
2	E	10	3.54217	4.07083	-5.0318	0.00366
3	E	15	3.77750	4.75083	-2.9946	0.02008
4	E	20	3.93933	4.82150	-2.5233	0.03256
5	E	30	4.30783	4.91558	-2.5069	0.03314
6	E	35	3.87117	4.89633	-3.5325	0.01209
7	E	45	6.18067	5.37867	3.7233	0.98979
8	E	50	6.42067	5.62533	5.2286	0.99681
9	F	15	1.29083	0.97033	2.9148	0.97827
10	F	20	1.18383	0.99483	3.1811	0.98325
11	F	25	1.61417	0.96167	4.1911	0.99310
12	F	30	1.88783	1.15792	10.3536	0.99975
13	F	35	1.70867	1.18483	3.3788	0.98609
14	F	40	1.84733	1.24500	4.5117	0.99464
15	F	45	2.18500	1.21717	7.8966	0.99930
16	F	50	2.54333	1.68183	4.7058	0.99537
17	H	35	4.14100	3.36983	2.1447	0.95072
18	H	50	4.50717	3.89500	2.6918	0.97272
19	T	5	2.26850	2.65867	-2.2654	0.04308
20	T	10	2.37800	2.84950	-4.1266	0.00727

TABLE 2-1C. T-TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES IN NO_x EMISSIONS.

T-Test Number	Car Model	Mileage Interval	Mean Emissions (gpvm)		T-Test [Clear-HiTEC 3000]	P-Value
			Clear	HiTEC 3000		
1	C	35	0.37083	0.22367	3.3740	0.98603
2	C	40	0.38233	0.22600	3.9062	0.99128
3	C	45	0.51117	0.33667	2.4035	0.96296
4	D	25	0.33200	0.40833	-4.9357	0.00797
5	D	50	0.37750	0.48300	-14.7972	0.00033
6	E	5	0.26850	0.21417	2.8768	0.97742
7	E	10	0.35467	0.25667	5.1771	0.99669
8	F	10	0.73483	0.66100	2.4188	0.96357
9	F	15	0.83267	0.70100	2.8756	0.97739
10	F	20	0.81033	0.66900	3.9606	0.99167
11	F	25	0.82667	0.69317	2.8260	0.97623
12	F	30	0.89583	0.63050	5.7267	0.99770
13	F	35	0.93417	0.66783	2.7665	0.97474
14	F	40	0.93250	0.67867	3.0256	0.98053
15	F	45	0.91233	0.67233	2.3932	0.96255
16	G	1	0.14200	0.17333	-2.7837	0.02481
17	H	50	0.45300	0.35100	2.8418	0.97661
18	T	10	0.82717	0.48933	2.2370	0.95554
19	T	15	0.84833	0.48317	4.2123	0.99322
20	T	20	0.83817	0.47683	9.3873	0.99964
21	T	25	0.71383	0.46700	6.7096	0.99872
22	T	30	0.62450	0.47583	3.3739	0.98603
23	T	35	0.76017	0.53067	3.3881	0.98621
24	T	40	0.80550	0.64367	4.4599	0.99442
25	T	50	0.77867	0.62917	2.1485	0.95093

of Model T cars and most of the time in Model E cars. Note that this analysis simply compares CO emissions for both fuels and does not consider the tailpipe emission standard. No mean CO emissions for Models F or T in Table 1B exceed the 3.4 gpvm standard. However, with one exception, mean CO emissions for Model E and H always exceed the standard for both fuels.

Referring to Table 2-1C, we see that there are three cases where HiTEC 3000 results in statistically significant, higher NO_x emissions than clear fuel, but 22 cases where HiTEC 3000 results in lower NO_x emissions than clear fuel. HiTEC 3000 appears to yield statistically significant lower NO_x emissions than clear fuel consistently in Models T and F and sometimes in Models C, H, and E. There are two mileage intervals for Model D cars where HiTEC 3000 NO_x emissions are higher than clear fuel. Also, note t-test number 16. This is the only case in which an initial 1,000 mile t-test indicates a significant difference in emissions among cars that are destined to use different fuels. In other words, with the exception of Model G cars, the clear fuel fleet and the HiTEC 3000 fleet had statistically equivalent emissions when the test program began. The three Model G cars that burned HiTEC 3000 actually began the test program with statistically significant, higher NO_x emissions than the three Model G cars that remained on clear fuel.

2.2 ANALYSIS OF VARIANCE (ANOVA) BY MILEAGE INTERVAL

In this analysis we pool the data by mileage interval. For example, at 20,000 miles we have 47 cars, which yield 47 HC measurements, 47 CO measurements, and 47 NO_x measurements. We fit a statistical model to the data that incorporates the effects of car model and fuel type. The statistical model then pools

information from all cars at each mileage interval. [The statistical model is based on execution of the SAS® procedure GLM.] Note that this model does not allow fuel effects to be model specific. That is, the statistical model does not include a term for potential Model x Fuel interaction. The model permits us to obtain an overall comparison of HiTEC 3000 versus clear fuel by mileage interval, but our statistical model may have an error term that is inflated. Since the statistical model does not include a term for potential Model x Fuel interaction, any variability associated with Model x Fuel interaction is imbedded in the error term. The effect of an inflated error term is that the t-statistic may be understated. An understated t-statistic could obscure an otherwise statistically significant difference. Statistical models used in subsequent analysis (see Sections 2.3.1 and 3.2) of the Ethyl emission data include a term to check for Model x Fuel interaction. However, we believe the results of our rather simplistic statistical model are interesting and informative, and we find several significant t-statistics.

In exercising the above-described statistical model, we obtain an overall emission estimate for the clear fuel fleet and for the HiTEC 3000 fleet at each mileage interval. We compute the difference in emissions and the P-values at each mileage interval to determine if the differences are significantly different from zero. Since the statistical model estimates average emissions at each mileage interval for each car model, we can also predict which car models and fuel types exceed the tailpipe emission standards, on average, at each mileage interval.

Table 2-2A lists the mileages, the differences between clear fuel and HiTEC 3000 hydrocarbon emissions, the P-value for testing whether the true difference between clear fuel and HiTEC 3000 HC emissions is zero, the error

TABLE 2-2A. MODELING RESULTS FOR HC EMISSIONS AS A FUNCTION OF MILEAGE.

Mileage	Difference in HC Emissions for Test Fleet [Clear-HiTEC 3000]	P-Value	MSE	Car Models Predicted to Exceed HC Standards Based on Average Emissions	
				HiTEC 3000	Clear Fuel
1	-.0000	1.000	.0002	--	--
5	-.0149	.004	.0003	--	--
10	-.0193	.002	.0004	--	--
15	-.0293	.000	.0006	D F	--
20	-.0329	.000	.0005	D F	D
25	-.0150	.127	.0011	D F	D F
30	-.0342	.000	.0008	D F	D F
35	-.0278	.005	.0010	D F	D F
40	-.0288	.016	.0015	D F T	D F T
45	-.0076	.603	.0024	D F T	D F T
50	-.0135	.405	.0030	D F T	D F T

mean square (MSE), and the car models that the underlying model predicts to exceed the 0.41 gpvm HC emission standard. Table 2-2A shows that HC emissions are lower for clear fuel than for HiTEC 3000 at every mileage interval. However, note that the differences in HC emissions are not statistically significant at 1,000 miles nor at 45,000 or 50,000 miles. From this observation, we offer the following conclusions.

- There was no true difference in HC emissions between the two fleet of cars when the HiTEC 3000 versus clear fuel tests began (i.e., 1,000 mile interval).
- HC emissions from cars with HiTEC 3000 initially increased faster than from those cars with clear fuel. However, this trend changed and by the end of the test program (i.e., 45,000 and 50,000 miles) there was no true difference in HC emissions between the two fleet of cars.

Lastly, Table 2-2A shows that three car models are predicted to exceed the 0.41 gpvm HC standard. Models D and F are predicted to exceed the standard earlier

with HiTEC 3000 than with clear fuel; Model T is predicted to exceed the standard at the same mileage interval on both fuels. It is very important that these exceedance predictions are not taken out of context. As discussed previously, the statistical model used to generate these predictions does not include a Model x Fuel interaction term. Second, and perhaps more importantly, our predictions say nothing about the magnitude by which the emission standard is exceeded. For example, the statistical model might predict HC emissions, at some mileage interval, to be 0.415 gpvm for Model F cars with HiTEC 3000 and 0.410 gpvm for Model F car with clear fuel. In this example, Model F cars with HiTEC 3000 would be predicted to exceed the HC emission standard, while Model F cars with clear fuel would be predicted to comply with the HC standard. This discussion regarding exceedance predictions is also applicable to subsequent predictions for CO and NO_x emission standards.

We repeat the above-described analysis for CO and report the results in Table 2-2B. We observe statistically significant differences at 45,000 and 50,000 miles with clear fuel having higher CO emissions than HiTEC 3000. We observe less significance than we might expect based on the results of t-tests, which are summarized in Table 2-1B. Where the t-tests are for individual car models (Table 2-1B), the statistically significant results are mixed, with some car models having higher CO emissions with HiTEC 3000 and other models having lower CO emissions with HiTEC 3000. In this analysis (Table 2-2B), the statistical model essentially averages the differences in CO emissions between clear fuel and HiTEC 3000 across all car models so the mixed results tend to negate one another in most cases (i.e., mileage intervals).

TABLE 2-2B. MODELING RESULTS FOR CO EMISSIONS AS A FUNCTION OF MILEAGE.

Mileage	Difference in CO Emissions for Test Fleet [Clear-HiTEC 3000]	P-Value	MSE	Car Models Predicted to Exceed CO Standards Based on Average Emissions	
				HiTEC 3000	Clear Fuel
1	-0.0683	0.3312	0.0577	--	--
5	-0.1245	0.1178	0.0727	--	--
10	-0.0347	0.7107	0.1010	E	E
15	-0.1385	0.2534	0.1670	E	E
20	-0.0901	0.3602	0.1108	ET	E
25	0.0950	0.3777	0.1290	ET	ET
30	-0.0618	0.5556	0.1265	ETHD	ETHD
35	-0.0117	0.9291	0.2010	ETHD	ETHD
40	-0.0336	0.8119	0.2305	ETHD	ETHD
45	0.2672	0.0481	0.2002	ETHD	ETHDC
50	0.3380	0.0335	0.2747	ETHD	ETHD

The results of the analysis for NO_x emissions are summarized in Table 2-2C. We observe that from 30,000 miles and beyond, clear fuel results in statistically higher NO_x emissions than does HiTEC 3000. We also note that the magnitude of the estimated difference in NO_x emissions increases with increasing mileage.

TABLE 2-2C. MODELING RESULTS FOR NO_x EMISSIONS AS A FUNCTION OF MILEAGE.

Mileage	Difference in NO _x Emissions for Test Fleet [Clear-HiTEC 3000]	P-Value	MSE	Car Models Predicted to Exceed NO _x Standards Based on Average Emissions	
				HiTEC 3000	Clear Fuel
1	-.0147	0.5409	0.0068	--	--
5	0.0328	0.2799	0.0104	--	--
10	0.0497	0.1450	0.0130	--	--
15	0.0637	0.0430	0.0108	--	--
20	0.0620	0.0670	0.0126	--	--
25	0.0515	0.0584	0.0079	--	--
30	0.0491	0.0493	0.0068	--	--
35	0.0672	0.0199	0.0089	--	--
40	0.0727	0.0027	0.0060	--	--
45	0.0850	0.0007	0.0062	--	--
50	0.1039	0.0202	0.0215	--	F

2.3 FITTING AND ANALYSIS OF QUADRATIC FUNCTIONS

In this phase of the analysis, we describe the pattern of emissions over time (i.e., increasing mileage) using a simple polynomial. A quadratic equation appears to capture the overall trend for most of the individual cars for all three pollutants. For example, for hydrocarbon emissions, only two of the 47 cars indicated such lack of fit at the 5 percent significance level, and 2 cars represent about 5 percent of the fleet of 47 cars. Where there are a few cases in which a cubic term is statistically significant, indicating that a more complicated function of mileage might provide a better fitting model, we analyzed the data using quadratic functions because we believe that the quadratic functions adequately represent overall emission trends for the fleet.

In addition to selecting the form of the equation (i.e., quadratic versus cubic), we also had to address how to use the 1,000-mile emission measurements. Clearly, the emissions measurements made at 1,000 miles for cars that subsequently burned HiTEC 3000 cannot be used to describe the emissions for HiTEC 3000 cars. That is, since none of the cars burned HiTEC 3000 prior to the 1,000 mile measurement point, the emission data cannot reflect any effects that might be attributed to HiTEC 3000. The disposition of the 1,000-mile data for clear cars is less straightforward. It is our considered opinion that use of the 1,000-mile data for clear cars in the analysis could provide unjustified leverage for these data points and could bias the results.

Therefore, our best statistical judgment is that all 1,000-mile data should be omitted for the purpose of fitting quadratic functions to the emission data.

Having made this decision, we proceed to fit the data and develop 141 (47 cars x 3 pollutants) quadratic equations. The advantage to reducing the time plots (i.e., emissions versus mileage) to quadratic equations for each car and pollutant is that we can compute analysis variables from the functions. In this report, we focus on two analysis variables: average emissions, denoted as AVG and exceedance mileage, denoted as CROSS. These analysis variables are computed from the above-described quadratic equations.

2.3.1 Average Emissions

The variable AVG represents average emissions and is equal to the integral of the quadratic function from 1,000 miles to 50,000 miles divided by 49,000 miles. This, of course, is the formula from calculus for finding the mean value of a function in an interval. Average emissions (i.e., AVG values) for each car and each pollutant are summarized in Tables 2-3A, 2-3B, and 2-3C.

Next we run statistical models for AVG to determine if there are fuel effects and to check for interaction (i.e., determine if the fuel effects are car model specific or if there is one common effect for all car models). [Remember that the statistical model we discussed in Section 2.2 did not account for or allow for fuel effects to be car model specific.] Table 2-4 summarizes these modeling results. The three pertinent rows of Table 2-4 are those labeled "FUEL*MODEL".

The first "FUEL*MODEL" row tells us that average CO emissions depend on fuel in a car model-specific way. That is, the P-value is 0.0168, which is much less than our designated significance level of 0.05. The second "FUEL*MODEL" row indicates that average hydrocarbon emissions depend on fuel in a common

TABLE 2-3A. AVERAGE HC EMISSIONS DETERMINED FROM FITTED QUADRATICS.

Car Model	Car Number	Type of Fuel	Average Emissions (gpvm)
C	1	Clear	0.18191
C	2	HiTEC	0.20878
C	3	HiTEC	0.23381
C	4	Clear	0.16027
C	5	Clear	0.18088
C	6	HiTEC	0.20385
D	1	Clear	0.45005
D	2	Clear	0.48796
D	4	HiTEC	0.51011
D	5	HiTEC	0.51594
D	6	HiTEC	0.54095
E	1	HiTEC	0.18951
E	2	Clear	0.19672
E	3	Clear	0.15595
E	4	Clear	0.15202
E	5	HiTEC	0.18869
E	6	HiTEC	0.19536
F	1	HiTEC	0.47490
F	2	HiTEC	0.47856
F	3	HiTEC	0.47647
F	4	Clear	0.43480
F	5	Clear	0.49258
F	6	Clear	0.50547
G	1	Clear	0.12672
G	2	Clear	0.12792
G	3	HiTEC	0.17395
G	4	Clear	0.13141
G	5	HiTEC	0.14576
G	6	HiTEC	0.15437
H	1	Clear	0.27184
H	2	Clear	0.28247
H	3	HiTEC	0.25379
H	4	HiTEC	0.24326
H	5	Clear	0.25894
H	6	HiTEC	0.30496
I	1	Clear	0.19494
I	2	HiTEC	0.21081
I	3	Clear	0.18288
I	4	HiTEC	0.18184
I	5	Clear	0.17692
I	6	HiTEC	0.18414
T	1	HiTEC	0.37183
T	2	Clear	0.30688
T	3	Clear	0.32823
T	4	HiTEC	0.35133
T	5	HiTEC	0.33319
T	6	Clear	0.30789

TABLE 2-3B. AVERAGE CO EMISSIONS DETERMINED FROM FITTED QUADRATICS.

Car Model	Car Number	Type of Fuel	Average Emissions (gpvm)
C	1	Clear	2.59537
C	2	HiTEC	2.75418
C	3	HiTEC	2.92741
C	4	Clear	2.09137
C	5	Clear	2.70313
C	6	HiTEC	2.26694
D	1	Clear	3.45757
D	2	Clear	3.53334
D	4	HiTEC	3.34918
D	5	HiTEC	3.41879
D	6	HiTEC	3.83424
E	1	HiTEC	4.99511
E	2	Clear	4.44610
E	3	Clear	4.43696
E	4	Clear	4.29867
E	5	HiTEC	4.83912
E	6	HiTEC	4.78940
F	1	HiTEC	1.07466
F	2	HiTEC	1.05563
F	3	HiTEC	1.08744
F	4	Clear	1.48662
F	5	Clear	1.61424
F	6	Clear	1.58295
G	1	Clear	1.90341
G	2	Clear	1.84647
G	3	HiTEC	1.83490
G	4	Clear	1.77649
G	5	HiTEC	1.85891
G	6	HiTEC	1.76068
H	1	Clear	3.28159
H	2	Clear	3.15599
H	3	HiTEC	2.80067
H	4	HiTEC	2.54380
H	5	Clear	3.28927
H	6	HiTEC	3.39643
I	1	Clear	2.52049
I	2	HiTEC	2.69097
I	3	Clear	2.34413
I	4	HiTEC	2.12114
I	5	Clear	2.19955
I	6	HiTEC	2.18956
T	1	HiTEC	4.04287
T	2	Clear	3.66967
T	3	Clear	3.91338
T	4	HiTEC	3.78319
T	5	HiTEC	3.70957
T	6	Clear	3.54759

TABLE 2-3C. AVERAGE NO_x EMISSIONS DETERMINED FROM FITTED QUADRATICS.

Car Model	Car Number	Type of Fuel	Average Emissions (gpvm)
C	1	Clear	0.33559
C	2	HiTEC	0.28644
C	3	HiTEC	0.28639
C	4	Clear	0.43022
C	5	Clear	0.29229
C	6	HiTEC	0.24566
D	1	Clear	0.46688
D	2	Clear	0.41497
D	4	HiTEC	0.47954
D	5	HiTEC	0.49403
D	6	HiTEC	0.48227
E	1	HiTEC	0.31636
E	2	Clear	0.36988
E	3	Clear	0.36830
E	4	Clear	0.34698
E	5	HiTEC	0.34292
E	6	HiTEC	0.36032
F	1	HiTEC	0.68251
F	2	HiTEC	0.70314
F	3	HiTEC	0.63611
F	4	Clear	0.91723
F	5	Clear	0.85770
F	6	Clear	0.77154
G	1	Clear	0.34622
G	2	Clear	0.36836
G	3	HiTEC	0.36332
G	4	Clear	0.37568
G	5	HiTEC	0.32995
G	6	HiTEC	0.36943
H	1	Clear	0.32958
H	2	Clear	0.33176
H	3	HiTEC	0.48802
H	4	HiTEC	0.55769
H	5	Clear	0.51116
H	6	HiTEC	0.29477
I	1	Clear	0.38726
I	2	HiTEC	0.41159
I	3	Clear	0.37836
I	4	HiTEC	0.32576
I	5	Clear	0.47915
I	6	HiTEC	0.39840
T	1	HiTEC	0.57533
T	2	Clear	0.74960
T	3	Clear	0.69885
T	4	HiTEC	0.51798
T	5	HiTEC	0.46868
T	6	Clear	0.85749

TABLE 2-4. ANOVA ON AVERAGE EMISSIONS.

-----Average CO Emissions-----					
Dependent Variable: AVG					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	1	0.00672270	0.00672270	0.15	0.7040
MODEL	7	49.18323007	7.02617572	153.67	0.0001
FUEL*MODEL	7	0.94925476	0.13560782	2.97	0.0168
-----Average HC Emissions-----					
Dependent Variable: AVG					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	1	0.01194921	0.01194921	34.39	0.0001
MODEL	7	0.75498389	0.10785484	310.39	0.0001
FUEL*MODEL	7	0.00428542	0.00061220	1.76	0.1310
-----Average NO _x Emissions-----					
Dependent Variable: AVG					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	1	0.04366945	0.04366945	11.63	0.0018
MODEL	7	1.04671808	0.14953115	39.81	0.0001
FUEL*MODEL	7	0.11352429	0.01621776	4.32	0.0020

way for all car models. That is, there is no significant interaction because the P-value is 0.1310. Note that "common to all car models" or "no significant interaction" simply means that the effect of switching from clear fuel to HiTEC 3000 appears to be the same for all car models. The last "FUEL*MODEL" row of Table 4 shows that average NO_x emissions are very dependent on fuel in a car model specific way (i.e., P-value = 0.0020).

Before proceeding to the next step of our analysis, which is to estimate the overall effects of switching from clear fuel to HiTEC 3000, we elaborate on the importance of the previous discussion regarding "interaction". We found that average CO and NO_x emissions depend on fuel in a car model-specific way,

but that average HC emissions depend on fuel in a common way for all car models. This means that we can estimate an overall fuel effect on HC emissions that not only describes the effect on the fleet but that is also relevant to each car model. On the other hand, estimated overall fuel effects on CO and NO_x emissions describe the effects on the fleet but do not necessarily characterize any particular car model. For example, if we find a 10 percent overall change in average NO_x emissions, it does not necessarily mean that any specific car model exhibited a 10 percent change but that the combined effect on fleet is a 10 percent change in average emissions.

Our analysis to determine overall fuel effects is completed by running the indicated statistical models. Using the SAS® Procedure GLM, the coefficient on HiTEC_CLEAR multiplied by 2 is our best estimate of the change in average emissions one would expect by switching from clear fuel to HiTEC 3000. The SAS® computer outputs are provided as Attachments 2B-1, 2B-2, and 2B-3. From Attachment 2B-1, we see that HiTEC 3000 increases average HC emissions by a statistically significant amount (i.e., P-value = 0.0004). Our best estimate of the increase is given by $2 \times (0.011315) = 0.023$ gpvm.

Turning to Attachment 2B-2, we estimate the overall fuel effect on average CO emissions. Unlike Attachment 2B-1, Attachment 2B-2 contains "HiTEC_CLR(Model)" entries because we determined that the fuel effect on average CO emissions is car-model specific. To better explain how to interpret the results shown in the attachments, we reproduce the following row from Attachment 2B-2.

HiTEC_CLR(Model)	C	<u>0.093112285</u>	1.07	<u>0.2944</u>	0.08729626
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This row tells us that switching from clear fuel to HiTEC 3000 in car Model C increases average CO emissions by $2 \times (.09311) = 0.186$ gpvm, but this is not

statistically distinguishable from zero since the P-value of 0.2944 is much greater than 0.05. The fourth row of Attachment 2B-2 indicates that switching from clear fuel to HiTEC 3000 in car Model F decreases average CO emissions by $2 \times (0.24435) = 0.489$ gpvm, and the result is statistically significant (i.e., P-value = 0.0098). On the other hand, switching from clear fuel to HiTEC 3000 in car Model E increases average CO emissions by a statistically significant amount (i.e., $2 \times (0.24032) = 0.481$ gpvm). Overall, the effect of switching from clear fuel to HiTEC 3000 is a statistically insignificant decrease in average CO emissions of 0.003 gpvm.

Attachment 2B-3 shows that effect of switching fuels on average NO_x emissions. Like CO emissions, the fuel effect on average NO_x emissions is very dependent on car model. The effect on average NO_x emissions is statistically significant for two car Models, F and T. Switching from clear fuel to HiTEC 3000 in car Model F results in a decrease in average NO_x emissions of $2 \times (0.08745) = 0.175$ gpvm. Switching from clear fuel to HiTEC 3000 in car Model T results in a decrease in average NO_x emissions of $2 \times (0.12399) = 0.248$ gpvm. The combined or overall effect on average NO_x emissions due to switching from clear fuel to HiTEC 3000 is a statistically significant decrease of 0.059 gpvm.

We conclude our analysis of differences in average emissions by providing a graphical presentation of the quadratic analysis. Figures 2-1, 2-2, and 2-3 show the quadratic trend for each pollutant, averaged across all clear-fuel cars and across all HiTEC 3000 cars. The graphs also show the data points upon which the quadratic curves are based.

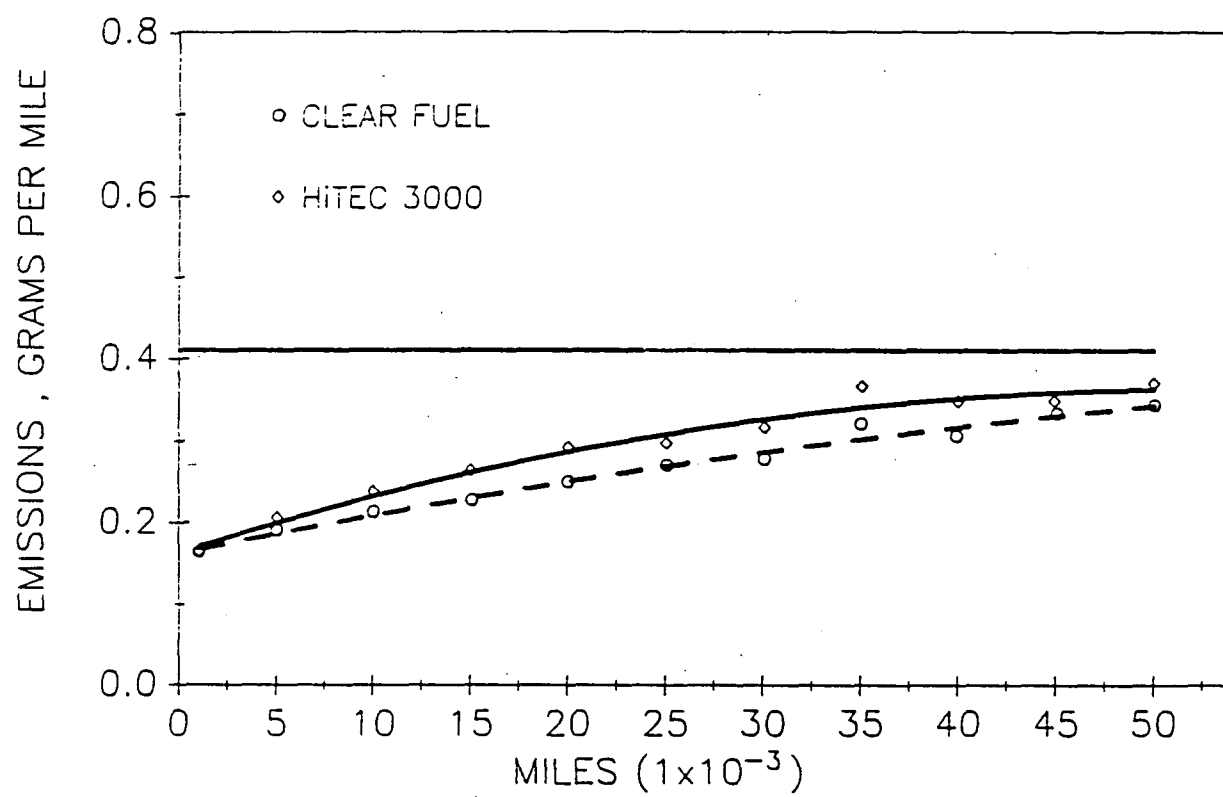


Figure 2-1. Quadratic trend of HC emissions averaged across all car models.

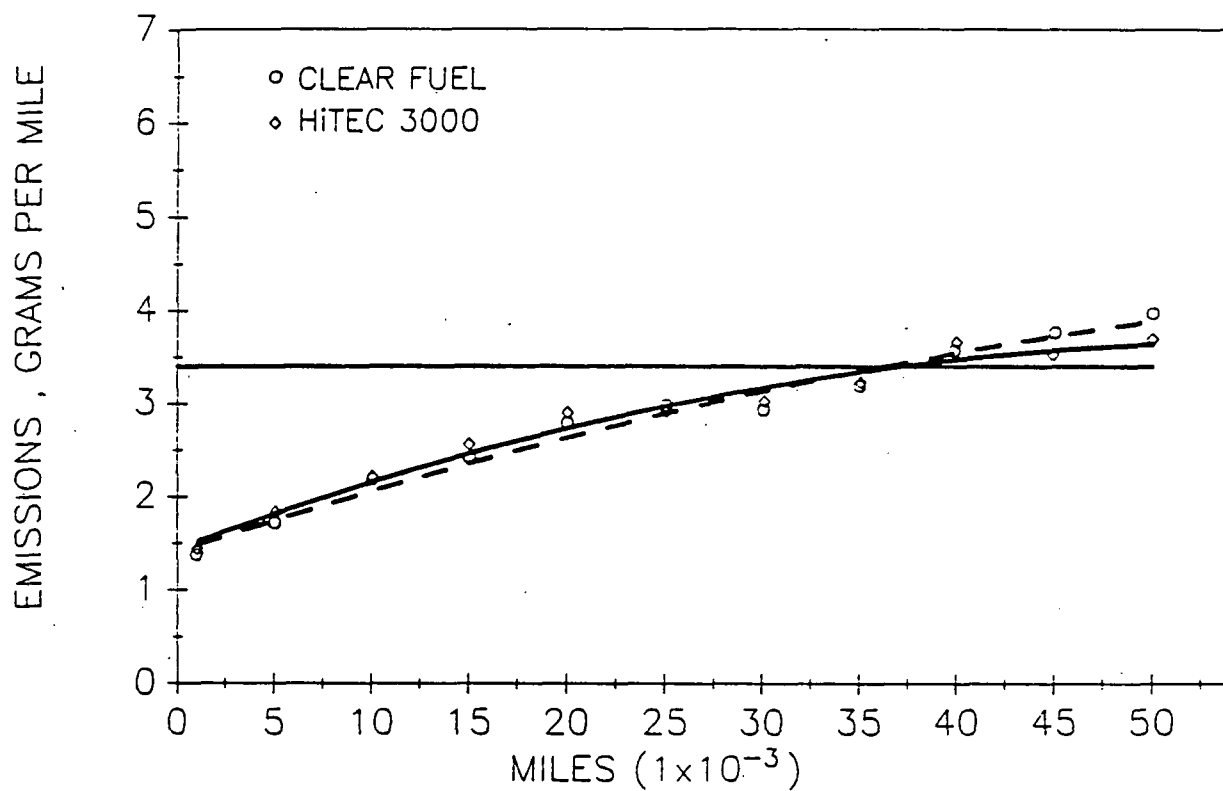


Figure 2-2. Quadratic trend of CO emissions averaged across all car models.

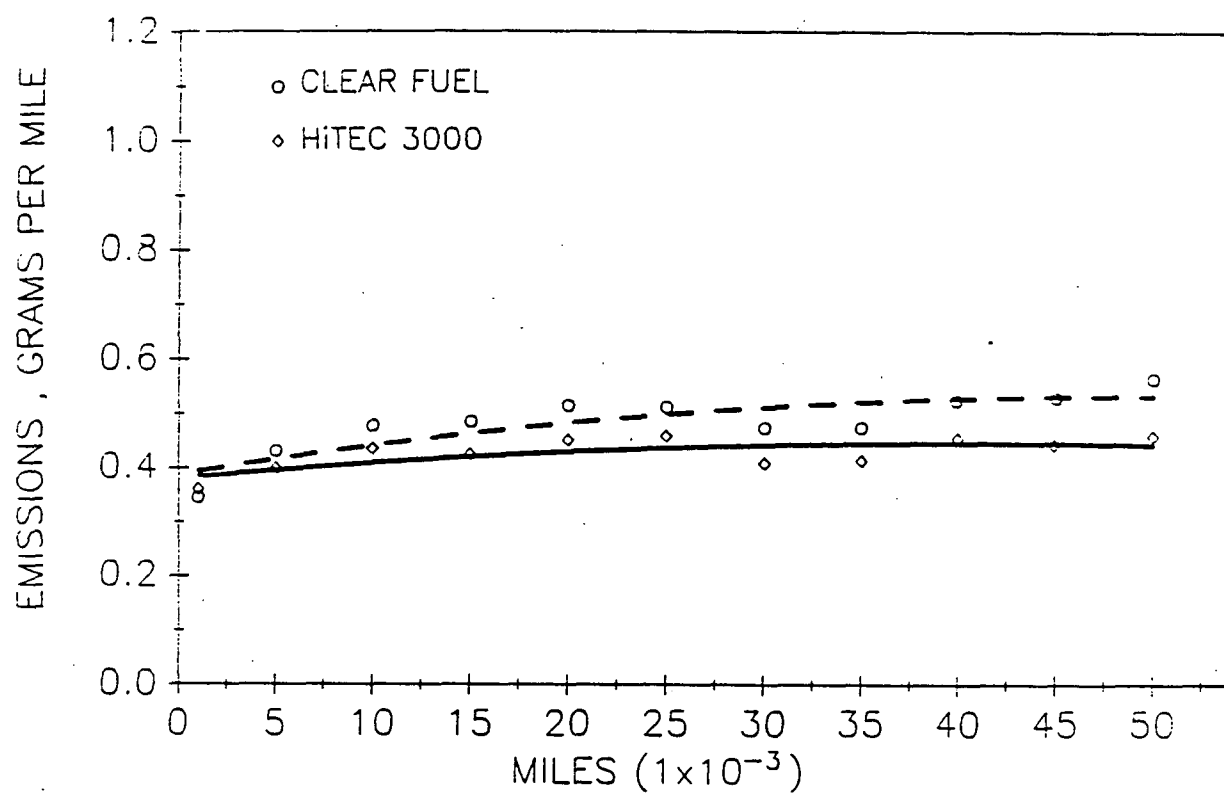


Figure 2-3. Quadratic trend of NO_x emissions averaged across all car models.

2.3.2 Exceedance Mileage

The next analysis variable we examine is CROSS, which is defined to be the mileage at which a car is predicted to exceed a tailpipe emission standard. In this analysis, we identify cars that are predicted to exceed one or more of the emission standards and then determine if clear fuel or HiTEC 3000 is associated with those exceedances.

There are three car models (i.e., T, F, and D) whose quadratic functions exceed the 0.41 gpvm HC standard. We compute the mileage at which each car is predicted to exceed the standard. We are able to conduct a fairly robust analysis because for each car model either: (1) no cars exceeded the standard or (2) all six cars exceeded the standard within (or very shortly after) the 0 to 50,000 mile interval.

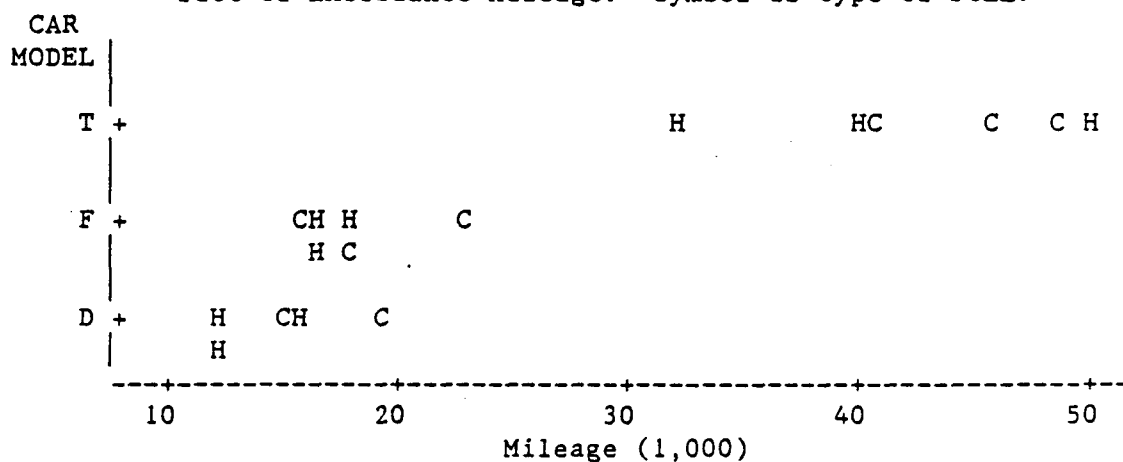
Table 2-5 presents a listing and plot of the data using only the three car models whose quadratic functions exceed the 0.41 gpvm standard. [One of the Model T cars actually exceeds the standard just beyond 50,000 miles; however, its omission would bias the results.] In Table 2-5, the columns "A", "B", and "C" are the constant, linear, and quadratic coefficients of each trend curve.

Note from the plot (shown at the bottom of Table 2-5) the variation in exceedance mileages -- even within car model. Our analysis indicates that this variability renders the exceedance mileages for the two fuels indistinguishable. In other words, HiTEC 3000 does not appear to cause or contribute to exceedances of the HC emission standard. The error mean squares suggest that the three car models should not be pooled (see Attachment 2B-4), but even pooling Models D, T, and F does not produce significant effects in

TABLE 2-5. QUADRATIC TRENDS FOR EACH CAR THAT EXCEEDS HC EMISSION STANDARD.

Car Model	Car Number	Fuel	Exceedance Mileage	Coefficients		
				A	B	C
D	6	HiTEC	11,836	0.21670	0.018321	-.00016810
D	4	HiTEC	12,278	0.17097	0.023064	-.00029282
D	2	Clear	14,954	0.19723	0.016527	-.00015371
D	5	HiTEC	15,512	0.28916	0.006831	0.00006184
F	5	Clear	15,626	0.20321	0.014897	-.00010642
F	1	HiTEC	16,274	0.21383	0.013786	-.00010640
F	2	HiTEC	16,632	0.19527	0.014702	-.00010774
F	3	HiTEC	17,780	0.19722	0.013129	-.00006533
F	6	Clear	17,835	0.22361	0.009759	0.00003881
D	1	Clear	18,950	0.23215	0.010491	-.00005835
F	4	Clear	22,581	0.17750	0.010728	-.00001912
T	1	HiTEC	32,307	0.22855	0.005537	0.00000246
T	4	HiTEC	39,663	0.24759	0.003929	0.00000417
T	3	Clear	40,748	0.21584	0.002796	0.00004832
T	2	Clear	45,494	0.24592	-0.000947	0.00010010
T	6	Clear	48,559	0.21737	0.002636	.00002741
T	5	HiTEC	50,098	0.22248	0.005533	-.00003573

Plot of Exceedance Mileage. Symbol is type of FUEL.



exceedance mileages. We suspect that this is due in part to the large component of the error sum of squares coming from the Model T cars.

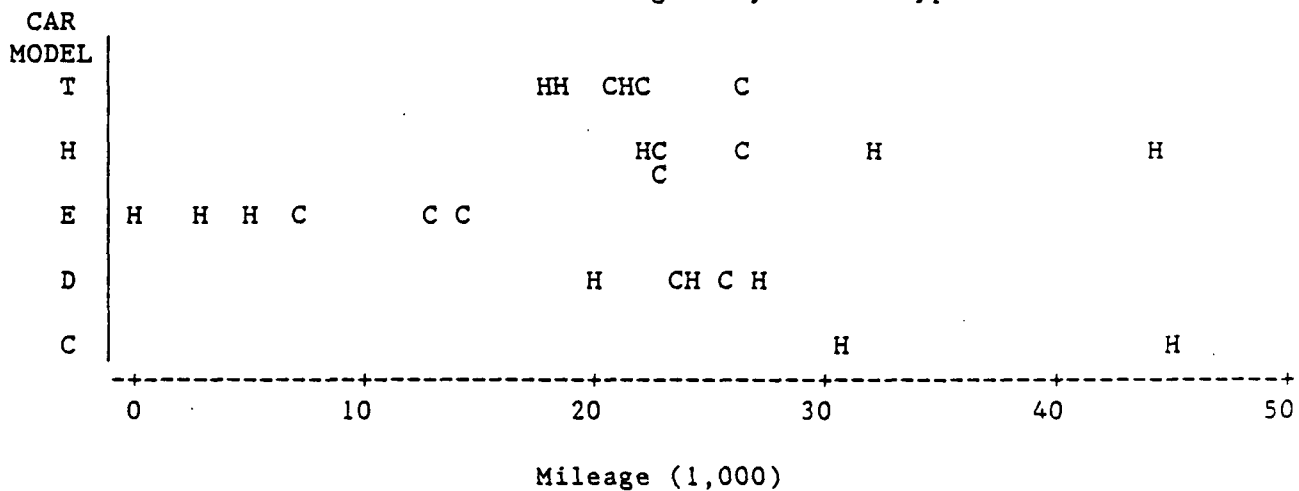
Table 2-6 presents a listing and plot of exceedance mileage for those cars that are predicted to exceed the CO emission standard. Car C-3, which was an HiTEC 3000 car, just exceeded the CO emission standard at about 31,000 miles. Predicted emissions peaked at 3.43 gpvm, and emissions dropped below the standard at about 40,000 miles. Car C-2, also an HiTEC 3000 car, exceeded the CO standard at approximately 46,000 miles; emissions peaked at 3.47 gpvm. No other model C car exceeded the standard. Thus, there is no comparison of clear fuel to HiTEC 3000 for model C, and these data points (i.e., for Cars C-2 and C-3) will not affect our CO analysis.

All individual cars within models D, E, H, and T eventually exceed the CO emission standard. For the other car models (i.e., C, F, G, and I), all test cars stayed below the standard throughout the test. A statistical representation without interaction (i.e., an overall effect rather than a car specific fuel effect) suggests a strong effect of car model and no difference between clear fuel and HiTEC 3000. However, a representation allowing interaction indicates that there are car-specific effects. These effects are broken out by a representation calling for a fuel comparison within each model of car. The computer output for this analysis is presented as Attachment 2B-5.

TABLE 2-6. QUADRATIC ANALYSIS OF EACH CAR THAT EXCEEDS CO EMISSION STANDARD.

Car Model	Car Number	Fuel	Exceedance Mileage
E	5	HiTEC	0
E	1	HiTEC	2,823
E	6	HiTEC	4,734
E	3	Clear	7,470
E	2	Clear	13,192
E	4	Clear	14,585
T	5	HiTEC	17,626
T	4	HiTEC	18,540
D	6	HiTEC	19,936
T	6	Clear	20,475
T	1	HiTEC	21,363
H	6	HiTEC	21,908
T	3	Clear	22,098
H	1	Clear	22,177
H	5	Clear	22,942
D	2	Clear	23,292
D	5	HiTEC	24,326
D	1	Clear	25,911
T	2	Clear	26,567
H	2	Clear	26,724
D	4	HiTEC	26,790
C	3	HiTEC	30,844
H	3	HiTEC	32,091
H	4	HiTEC	44,396
C	2	HiTEC	46,430

Plot of Exceedance Mileage. Symbol is type of FUEL.



From Attachment 2B-4 we see that HiTEC_CLR has a negative coefficient 4.615... for car Model E and a positive coefficient -4.425... for car Model H. In this particular statistical representation, the coefficient is multiplied by HiTEC_CLR, which is 1 for clear fuel and -1 for HiTEC 3000. Thus, this representation predicts a difference in exceedance mileage equal to twice the coefficient. Specifically, this representation predicts that Model E cars with clear fuel will exceed the CO standard $2 \times 4.615 = 9,230$ miles after HiTEC 3000 cars exceed the standard. On the other hand, an opposite and almost equal effect is observed for Model H cars. That is, Model H cars with clear fuel will exceed the CO standard $2 \times 4.425 = 8,850$ miles before HiTEC 3000 cars exceed the standard. No other car models show statistically significant effects. Thus, on balance, these effects tend to negate one another.

The quadratic trends for only two individual cars exceed the NO_x emission standard of 1.0 gpvm. Car T-6 is predicted to exceed the standard at 0 miles but is predicted to cross below the standard after about 12,000 miles. Car F-4 starts below the standard, but is predicted to exceed the standard at about 34,000 miles. Both cars T-6 and F-4 burned clear fuel; however, we cannot attribute statistical significance to this observation. That is, when an individual car is predicted to exceed an emission standard, the probability is 0.5 that the car is burning clear fuel. The occurrence of two events, each having a probability of 0.5, is not statistically significant. When only cars burning one type of fuel exceed the standard, at least 5 cars must exceed the standard in order to have statistical significance at or above the 95 percent level.

3. ANALYSIS OF 75,000-MILE DATA

In this section of the report, we repeat the analysis described in Section 2 for the 75,000-mile emission test data.

3.1 SIMPLE STATISTICS

For the 75,000-mile data there are 128 t-tests (8 car models x 16 mileage intervals) for each of the three pollutants. We present the results of the t-tests in Tables 3-1A, 3-1B, and 3-1C for those cars where emissions are statistically different between HiTEC 3000 and clear fuel.

Referring to Table 3-1A, we see that there are 32 cases where HiTEC 3000 results in statistically significant, higher HC emissions than does clear fuel, and one case where clear fuel results in higher HC emissions. If there were no true differences between the two fuels, natural sampling variability would lead us to expect about seven cases ($0.05 \times 128 = 6.4$) in each of the two categories. Thus, HiTEC 3000 appears to result in slightly higher HC emissions than clear fuel, and this effect also appears to be a function of the car model being examined. That is, four car models (C, E, G, and T) account for 27 of the 32 t-tests in which HiTEC 3000 results in statistically significant, higher HC emissions. Also note that only seven of the 32 significant t-tests occur after the 50,000-mile interval.

Referring to Table 3-1B, we see that there are nine cases (out of 128 t-tests) where HiTEC 3000 results in significantly higher CO emissions than does clear fuel; however, there are 21 cases where clear fuel results in higher CO emissions. Again, if there were no fuel effect on emissions, natural sampling

TABLE 3-1A. T-TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES IN HC EMISSIONS.

T-Test Number	Car Model	Mileage Interval	Mean Emissions (gpvm)		T-Test [Clear-HiTEC 3000]	P-Value
			Clear	HiTEC 3000		
1	C	15	0.15750	0.20400	-3.2088	0.01631
2	C	20	0.18950	0.23933	-7.0825	0.00105
3	C	25	0.17900	0.21400	-3.3627	0.01412
4	C	30	0.17492	0.21997	-3.3485	0.01430
5	C	40	0.17517	0.23900	-3.7623	0.00987
6	C	70	0.20767	0.25383	-3.2491	0.01570
7	D	20	0.44100	0.51917	-2.9177	0.03080
8	E	5	0.13067	0.16100	-4.6893	0.00469
9	E	10	0.15450	0.18067	-2.8030	0.02433
10	E	15	0.14767	0.19000	-2.9820	0.02033
11	E	20	0.15567	0.20217	-3.6073	0.01131
12	E	30	0.17108	0.19483	-2.4518	0.03515
13	F	20	0.39900	0.42183	-2.7618	0.02538
14	G	15	0.10550	0.14150	-5.4170	0.00281
15	G	20	0.13550	0.17150	-3.9675	0.00829
16	G	25	0.14033	0.17333	-2.5460	0.03179
17	G	35	0.13550	0.18183	-3.2254	0.01606
18	G	40	0.13917	0.18217	-2.2721	0.04276
19	G	45	0.13767	0.17067	-2.1752	0.04763
20	G	60	0.12975	0.16875	-3.1060	0.01801
21	G	65	0.14817	0.18900	-2.1480	0.04910
22	G	70	0.16367	0.18617	-2.1820	0.04727
23	G	75	0.16067	0.19733	-2.4431	0.03549
24	H	35	0.32083	0.27450	2.6704	0.97211
25	I	40	0.17583	0.19417	-2.1730	0.04775
26	I	45	0.17783	0.20250	-2.5196	0.03269
27	I	65	0.18117	0.20017	-2.2240	0.04510
28	T	10	0.24450	0.29717	-10.5799	0.00023
29	T	20	0.27967	0.32833	-2.2226	0.04518
30	T	25	0.30483	0.34600	-2.4147	0.03659
31	T	30	0.30175	0.37175	-3.2845	0.01519
32	T	35	0.33500	0.39800	-3.0037	0.01990
33	T	60	0.36617	0.41039	-5.7832	0.00222

TABLE 3-1B. T-TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES IN CO EMISSIONS.

T-Test Number	Car Model	Mileage Interval	Mean Emissions (gpvm)		T-Test [Clear-HiTEC 3000]	P-Value
			Clear	HiTEC 3000		
1	D	55	5.39150	4.18050	3.1669	0.97470
2	D	60	6.36050	5.19508	3.0985	0.97332
3	E	5	2.65517	3.48400	-4.1926	0.00689
4	E	10	3.54217	4.07083	-5.0318	0.00366
5	E	15	3.77750	4.75083	-2.9946	0.02008
6	E	20	3.93933	4.82150	-2.5233	0.03256
7	E	30	4.30783	4.91558	-2.5069	0.03314
8	E	35	3.87117	4.89633	-3.5325	0.01209
9	E	45	6.18067	5.37867	3.7233	0.98979
10	E	50	6.42067	5.62533	5.2286	0.99681
11	E	55	6.07333	5.24217	2.7467	0.97423
12	F	15	1.29083	0.97033	2.9148	0.97827
13	F	20	1.18383	0.99483	3.1811	0.98325
14	F	25	1.61417	0.96167	4.1911	0.99310
15	F	30	1.88783	1.15792	10.3536	0.99975
16	F	35	1.70867	1.18483	3.3788	0.98609
17	F	40	1.84733	1.24500	4.5117	0.99464
18	F	45	2.18500	1.21717	7.8966	0.99930
19	F	50	2.54333	1.68183	4.7058	0.99537
20	F	60	2.81217	1.68075	8.3326	0.99943
21	F	65	3.00500	1.61783	6.2657	0.99834
22	F	70	2.90325	1.59500	11.1185	0.99600
23	F	75	2.22600	1.34825	17.6613	0.99840
24	G	60	2.05275	2.52475	-2.6848	0.02748
25	H	35	4.14100	3.36983	2.1447	0.95072
26	H	50	4.50717	3.94050	2.3779	0.96192
27	T	5	2.26850	2.65867	-2.2654	0.04308
28	T	10	2.37800	2.84950	-4.1266	0.00727
29	T	70	6.01267	5.43833	3.5950	0.98857
30	T	75	5.91283	4.74667	3.5485	0.98809

TABLE 3-1C. T-TESTS FOR STATISTICALLY SIGNIFICANT DIFFERENCES IN NO_x EMISSIONS.

T-Test Number	Car Model	Mileage Interval	Mean Emissions (gpvm)		T-Test [Clear-HiTEC 3000]	P-Value
			Clear	HiTEC 3000		
1	C	35	0.37083	0.22367	3.3740	0.98603
2	C	40	0.38233	0.22600	3.9062	0.99128
3	C	45	0.51117	0.33667	2.4035	0.96296
4	C	55	0.56117	0.35517	2.4173	0.96351
5	C	60	0.63392	0.39175	2.9712	0.97945
6	C	65	0.52150	0.34350	2.9223	0.97843
7	C	75	0.63683	0.40367	2.3639	0.96133
8	D	25	0.33200	0.40833	-4.9357	0.00797
9	D	50	0.37750	0.48050	-13.1758	0.00047
10	D	55	0.54975	0.48433	5.1015	0.99272
11	D	60	0.62712	0.56558	4.4419	0.98939
12	E	5	0.26850	0.21417	2.8802	0.97750
13	E	10	0.35467	0.25667	5.1795	0.99670
14	F	10	0.73483	0.66100	2.4188	0.96357
15	F	15	0.83267	0.70100	2.8756	0.97739
16	F	20	0.81033	0.66900	3.9606	0.99167
17	F	25	0.82667	0.69317	2.8260	0.97623
18	F	30	0.89583	0.63050	5.7267	0.99770
19	F	35	0.93417	0.66783	2.7665	0.97474
20	F	40	0.93250	0.67867	3.0256	0.98053
21	F	45	0.91233	0.67233	2.3932	0.96255
22	F	65	1.65717	0.83500	2.3963	0.96267
23	F	75	1.71000	0.77200	7.8980	0.99217
24	G	1	0.14200	0.17333	-2.7837	0.02481
25	G	55	0.37700	0.33900	2.6017	0.97003
26	G	65	0.44267	0.35267	2.3635	0.96132
27	H	50	0.45300	0.35100	2.8418	0.97661
28	H	55	0.42133	0.31017	3.0423	0.98084
29	H	60	0.42525	0.31967	3.5761	0.98838
30	H	65	0.42700	0.31767	2.8499	0.97680
31	H	70	0.42317	0.29283	4.5242	0.99469
32	H	75	0.44100	0.28633	24.4555	0.99999
33	I	60	0.46425	0.30975	2.1494	0.95098
34	T	10	0.82717	0.48933	2.2370	0.95554
35	T	15	0.84833	0.48317	4.2123	0.99322
36	T	20	0.83817	0.47683	9.3873	0.99964
37	T	25	0.71383	0.46700	6.7075	0.99871
38	T	30	0.62450	0.47583	3.3731	0.98602
39	T	35	0.76017	0.53067	3.3880	0.98621
40	T	40	0.80550	0.64367	4.4607	0.99442
41	T	50	0.77867	0.62917	2.1485	0.95093
42	T	60	0.88811	0.71800	2.1815	0.95271
43	T	70	0.88733	0.65983	4.6198	0.99506
44	T	75	0.88400	0.65633	5.0721	0.99644

variability would lead us to expect about seven cases in each of the two categories. HiTEC 3000 appears to yield significantly lower CO emissions than clear fuel in Model F cars and in the later mileage intervals of Model E and T cars. HiTEC 3000 appears to yield statistically significant, higher CO emissions than clear fuel in the very early mileage intervals of Model T cars and in early mileage intervals of Model E cars. Thus, the CO comparison for the two fuels appears to be a function of car model being examined, and for Models E and T, a function of accumulated mileage.

Referring to Table 3-1C, we see that there are three cases where HiTEC 3000 results in statistically significant, higher NO_x emissions than clear fuel, but 41 cases where HiTEC 3000 results in lower NO_x emissions than clear fuel. HiTEC 3000 appears to yield statistically significant lower NO_x emissions than clear fuel consistently in Models T and F and sometimes in Models C, H, and E. We also note that the number of cases where HiTEC 3000 results in lower NO_x emissions than clear fuel for the 75,000-mile data is almost twice that observed for the 50,000-mile data (i.e., 41 versus 22).

3.2 ANALYSIS OF VARIANCE (ANOVA)

3.2.1 ANOVA By Mileage Interval

In this analysis we pool the emission data by mileage interval and fit a statistical model to the data that incorporates the effects of car model and fuel type. This particular statistical model does not allow fuel effects to be car-model specific. That is, the statistical model does not include a term for potential Model x Fuel interaction.

In exercising the above-described statistical model, we obtain an estimate of emissions for the clear fuel fleet and for the HiTEC 3000 fleet at each mileage interval. We compute the difference in emissions and the P-values at each mileage interval to determine if the differences are statistically different from zero. Since the statistical model estimates average emissions at each mileage interval for each car model, we can also determine which car models and fuel types are predicted to exceed the tailpipe emission standards at each mileage interval.*

Table 3-2A lists the mileages, the differences between clear fuel and HiTEC 3000 hydrocarbon emissions, the P-value for testing whether the true difference between clear fuel and HiTEC 3000 emissions is zero, and the car models that the underlying statistical model predicts to exceed the 0.41 gpvm HC emission standard. Table 3-2A shows that HC emissions are lower for clear fuel than for HiTEC 3000 at every mileage interval. However, note that the differences in HC emissions are not statistically significant at 1,000 miles nor from 45,000 miles through the completion of the test program (i.e., 75,000 miles).

Lastly, Table 3-2A shows that four car models are predicted to exceed the 0.41 gpvm HC standard. Since three car models (D, F, and T) are predicted to exceed the standard prior to 50,000 miles, the discussion presented in Section 2 need not be repeated here. Model H is predicted to exceed the HC standard at 60,000 and 65,000 miles for both clear fuel and HiTEC 3000.

* For purposes of this analysis, the applicable emission standards are assumed to apply beyond 50,000 miles of vehicle operation.

TABLE 3-2A. MODELING RESULTS FOR HC EMISSIONS AS A FUNCTION OF MILEAGE.

Mileage	Difference in HC Emissions for Test Fleet [Clear-HiTEC 3000]	P-Value	MSE	Car Models Predicted to Exceed HC Standards	
				HiTEC 3000	Clear Fuel
1	0.000000	1.0000	.0002	--	--
5	-0.014937	0.0036	.0003	--	--
10	-0.019303	0.0018	.0004	--	--
15	-0.029389	0.0002	.0006	D F	--
20	-0.032910	0.0001	.0005	D F	D
25	-0.014974	0.1274	.0011	D F	D F
30	-0.034198	0.0002	.0008	D F	D F
35	-0.027842	0.0053	.0010	D F	D F
40	-0.028818	0.0162	.0015	D F T	D F T
45	-0.007585	0.6032	.0024	D F T	D F T
50	-0.013526	0.4046	.0030	D F T	D F T
55	-0.000662	0.9517	.0014	D F T	D F T
60	-0.020644	0.0867	.0016	D F H	D F H
65	-0.016701	0.4038	.0046	D F T H	D F T H
70	-0.013569	0.2503	.0015	D F	D F
75	-0.016991	0.2922	.0028	D F T	D F

We repeat the above-described analysis for CO and report the results in Table 3-2B. We observe statistically significant differences at 45,000, 50,000, 55,000, 60,000, and 70,000 miles with clear fuel having higher CO emissions than HiTEC 3000. Comparing these results with those presented in Table 2-2B, we observe the following trend with respect to increasing mileage. The difference between HiTEC 3000 CO emissions and clear fuel CO emissions appears to increase with increasing mileage -- with HiTEC 3000 emissions being lower than clear fuel emissions. The differences are statistically significant for three of the five high mileage intervals and almost significant at a fourth mileage interval (i.e., P-value = 0.0707 at 75,000 miles).

TABLE 3-2B. MODELING RESULTS FOR CO EMISSIONS AS A FUNCTION OF MILEAGE.

Mileage	Difference in CO Emissions for Test Fleet [Clear-HiTEC 3000]	P-Value	MSE	Car Models Predicted to Exceed CO Standards	
				HiTEC 3000	Clear Fuel
1	-0.06825	0.3312	.0577	--	--
5	-0.12450	0.1178	.0727	--	--
10	-0.03473	0.7107	.1010	E	E
15	-0.13855	0.2534	.1670	E	E
20	-0.09014	0.3602	.1108	E T	E
25	0.09498	0.3777	.1290	E T	E T
30	-0.06184	0.5556	.1265	E T D H	E T D H
35	-0.01173	0.9291	.2010	E T D H	E T D H
40	-0.03363	0.8119	.2305	E T D H	E T D H
45	0.26719	0.0481	.2002	E T D H	E T D H C
50	0.33801	0.0335	.2747	E T D H	E T D H
55	0.69408	0.0074	.7037	E T D H	E T D H
60	0.31420	0.0176	.1874	E T D H	E T D H
65	0.37085	0.1150	.6185	E T D H	E T D H
70	0.40591	0.0241	.3326	E T D H	E T D H
75	0.27042	0.0707	.2362	E T D H	E T D H

The results of the analysis for NO_x emissions are summarized in Table 3-2C.

We observe that from 30,000 miles and beyond, clear fuel results in statistically higher NO_x emissions than does HiTEC 3000. We also note that the magnitude of the estimated differences in NO_x emissions continues to increase with increasing mileage.

TABLE 3-2C. MODELING RESULTS FOR NO_x EMISSIONS AS A FUNCTION OF MILEAGE.

Mileage	Difference in NO _x Emissions for Test Fleet [Clear-HiTEC 3000]	P-Value	MSE	Car Models Predicted to Exceed NO _x Standards	
				HiTEC 3000	Clear Fuel
1	-0.01471	0.5409	.0068	--	--
5	0.03227	0.2799	.0104	--	--
10	0.04963	0.1452	.0130	--	--
15	0.06369	0.0430	.0108	--	--
20	0.06196	0.0670	.0126	--	--
25	0.05151	0.0584	.0079	--	--
30	0.04909	0.0493	.0068	--	--
35	0.06719	0.0199	.0089	--	--
40	0.07268	0.0027	.0060	--	--
45	0.08494	0.0007	.0062	--	--
50	0.10390	0.0202	.0215	--	F
55	0.16036	0.0004	.0200	F	F
60	0.17143	0.0012	.0282	F	F
65	0.21201	0.0011	.0421	F	F
70	0.15446	0.0114	.0376	F	F
75	0.19634	0.0003	.0269	F	F

3.2.2 ANOVA Combining Mileage Intervals

In our next analysis, we combine the emission data across mileage intervals for each car. We subject the average emissions to an analysis of variance that tests whether average emissions are functions of fuel type and, if so, if the effect of fuel depends on car model.

We copy the type I sum of squares for each SAS® GLM run (see Table 3-3). The P-values indicate that the comparison of HiTEC 3000 to clear fuel is significant for HC and NO_x. The variable HiTEC_CLR is 1 if the fuel is HiTEC 3000 and -1 if the fuel is clear. The coefficient is a number added to HiTEC 3000 cars and subtracted from clear fuel cars so that twice this coefficient is the effect of a switch from clear fuel to HiTEC 3000, with a positive number indicating an increase due to HiTEC 3000. The P-values in

Table 3-3 for HiTEC_CLR*MODEL indicate that the difference is model specific for CO and NO_x but not for HC.

TABLE 3-3. ANOVA FOR COMBINED MILEAGE INTERVALS.

----- Average HC Emissions -----					
Dependent Variable: MNHC					
	R-Square	C.V.	Root MSE	MNHC Mean	
	0.984272	7.423588	0.023240	0.31305335	
Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	7	1.04145181	0.14877883	275.47	0.0001
HiTEC_CLR	1	0.00492396	0.00492396	9.12	0.0050
HiTEC_CLR*MODEL	7	0.00137541	0.00019649	0.36	0.9163
----- Average CO Emissions -----					
Dependent Variable: MNCO					
	R-Square	C.V.	Root MSE	MNCO Mean	
	0.978032	7.181142	0.241137	3.35792417	
Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	7	79.01855264	11.28836466	194.13	0.0001
HiTEC_CLR	1	0.27611553	0.27611553	4.75	0.0370
HiTEC_CLR*MODEL	7	0.95581533	0.13654505	2.35	0.0479
----- Average NO _x Emissions -----					
Dependent Variable: MNNOX					
	R-Square	C.V.	Root MSE	MNNOX Mean	
	0.917647	14.43242	0.073301	0.50788866	
Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	7	1.57727461	0.22532494	41.94	0.0001
HiTEC_CLR	1	0.12837105	0.12837105	23.89	0.0001
HiTEC_CLR*MODEL	7	0.15034459	0.02147780	4.00	0.0032

The analysis summarized in Table 3-3 suggests that differences in emissions are car-model specific for average NO_x emissions and for average CO emissions; however, differences are not car-model specific for average HC emissions. We complete this part of the analysis by exercising the indicated statistical models. Using the SAS® Procedure GLM, the coefficient on HiTEC_Clear multiplied by 2 is our best estimate of the change in average emissions one

would expect by switching from clear fuel to HiTEC 3000. The SAS® computer outputs are provided as Attachments 2B-6, 2B-7, and 2B-8.

From Attachment 2B-6, we see that HiTEC 3000 increases average HC emissions by a statistically significant amount. Our best estimate of the increase is given by $2 \times (.010256) = 0.021$ gpvm. Attachment 2B-7 shows a statistically significant decrease in average CO emissions of 0.770 gpvm for Model F cars. Overall, the effect of switching from clear fuel to HiTEC 3000 is a decrease in average CO emissions of 0.155 gpvm. Attachment 2B-8 shows statistically significant differences in NO_x emissions for three car models. For these three car models (C, F, and T), average NO_x emissions are significantly lower for HiTEC 3000 than for clear fuel. The difference ranges from 0.135 to 0.333 gpvm. Overall, the effect of switching from clear fuel to HiTEC 3000 is a decrease in average NO_x emissions of 0.102 gpvm.

3.3 FITTING AND ANALYSIS OF QUADRATIC FUNCTIONS

In this phase of the analysis, we describe the pattern of emissions as a function of mileage using a simple polynomial. A quadratic equation captures the overall trend for the individual cars for all three pollutants. However, the degree of fit for the 75,000-mile data is not as good as for the 50,000-mile data. As with the 50,000-mile data analysis, we have omitted all 1,000-mile data for the purpose of fitting quadratic functions to the emission data.

The variable AVG represents average emissions and is equal to the integral of the quadratic function from 1,000 miles to 75,000 miles divided by the mileage interval (i.e., 74,000 miles). Average emissions for each car and each pollutant are summarized in Tables 3-4A, 3-4B, and 3-4C.

TABLE 3-4A. AVERAGE HC EMISSIONS DETERMINED FROM FITTED QUADRATICS.

Car Model	Car Number	Type of Fuel	Average Emissions (gpvm)
C	1	Clear	0.18531
C	4	Clear	0.16284
C	5	Clear	0.19340
C	2	HITEC	0.21137
C	3	HITEC	0.24245
C	6	HITEC	0.20514
D	1	Clear	0.53672
D	2	Clear	0.54502
D	4	HITEC	0.54688
D	5	HITEC	0.56681
D	6	HITEC	0.59099
E	2	Clear	0.24388
E	3	Clear	0.16963
E	4	Clear	0.16462
E	1	HITEC	0.20747
E	5	HITEC	0.20617
E	6	HITEC	0.20175
F	4	Clear	0.47434
F	5	Clear	0.50089
F	6	Clear	0.54833
F	1	HITEC	0.54127
F	2	HITEC	0.50742
F	3	HITEC	0.50608
G	1	Clear	0.13324
G	2	Clear	0.13542
G	4	Clear	0.13700
G	3	HITEC	0.18348
G	5	HITEC	0.15282
G	6	HITEC	0.16125
H	1	Clear	0.30355
H	2	Clear	0.32442
H	5	Clear	0.30830
H	3	HITEC	0.30034
H	4	HITEC	0.28829
H	6	HITEC	0.36773
I	1	Clear	0.19597
I	3	Clear	0.18538
I	5	Clear	0.17910
I	2	HITEC	0.21245
I	4	HITEC	0.18566
I	6	HITEC	0.18887
T	2	Clear	0.33968
T	3	Clear	0.35899
T	6	Clear	0.34114
T	1	HITEC	0.39045
T	4	HITEC	0.36976
T	5	HITEC	0.35993

TABLE 3-4B. AVERAGE CO EMISSIONS DETERMINED FROM FITTED QUADRATICS.

Car Model	Car Number	Type of Fuel	Average Emissions (gpvm)
C	1	Clear	2.67361
C	4	Clear	2.12968
C	5	Clear	2.80317
C	2	HiTEC	2.85124
C	3	HiTEC	2.99750
C	6	HiTEC	2.38793
D	1	Clear	4.29640
D	2	Clear	4.16479
D	4	HiTEC	3.89117
D	5	HiTEC	3.97372
D	6	HiTEC	4.42551
E	2	Clear	5.35159
E	3	Clear	5.00715
E	4	Clear	5.11753
E	1	HiTEC	5.37591
E	5	HiTEC	5.39423
E	6	HiTEC	5.04661
F	4	Clear	2.04602
F	5	Clear	1.97496
F	6	Clear	1.92064
F	1	HiTEC	1.26072
F	2	HiTEC	1.24079
F	3	HiTEC	1.20754
G	1	Clear	2.08284
G	2	Clear	1.95748
G	4	Clear	1.90162
G	3	HiTEC	2.01281
G	5	HiTEC	2.08121
G	6	HiTEC	1.98152
H	1	Clear	3.71730
H	2	Clear	3.57736
H	5	Clear	3.88732
H	3	HiTEC	3.43238
H	4	HiTEC	3.03003
H	6	HiTEC	3.80741
I	1	Clear	2.57055
I	3	Clear	2.58753
I	5	Clear	2.28933
I	2	HiTEC	2.67858
I	4	HiTEC	2.14449
I	6	HiTEC	2.29418
T	2	Clear	4.75260
T	3	Clear	4.95825
T	6	Clear	4.34551
T	1	HiTEC	4.92574
T	4	HiTEC	4.27613
T	5	HiTEC	4.28698

TABLE 3-4C. AVERAGE NO_x EMISSIONS DETERMINED FROM FITTED QUADRATICS.

Car Model	Car Number	Type of Fuel	Average Emissions (gpvm)
C	1	Clear	0.41329
C	4	Clear	0.51842
C	5	Clear	0.34160
C	2	HiTEC	0.32634
C	3	HiTEC	0.31236
C	6	HiTEC	0.26464
D	1	Clear	0.48391
D	2	Clear	0.44893
D	4	HiTEC	0.48632
D	5	HiTEC	0.50212
D	6	HiTEC	0.49522
E	2	Clear	0.43374
E	3	Clear	0.41009
E	4	Clear	0.37206
E	1	HiTEC	0.35408
E	5	HiTEC	0.37945
E	6	HiTEC	0.39078
F	4	Clear	1.22524
F	5	Clear	1.08125
F	6	Clear	0.88200
F	1	HiTEC	0.68679
F	2	HiTEC	0.82690
F	3	HiTEC	0.72276
G	1	Clear	0.36443
G	2	Clear	0.40406
G	4	Clear	0.38854
G	3	HiTEC	0.36760
G	5	HiTEC	0.34722
G	6	HiTEC	0.38014
H	1	Clear	0.35337
H	2	Clear	0.36219
H	5	Clear	0.49374
H	3	HiTEC	0.42715
H	4	HiTEC	0.48471
H	6	HiTEC	0.29587
I	1	Clear	0.39842
I	3	Clear	0.49204
I	5	Clear	0.47742
I	2	HiTEC	0.40685
I	4	HiTEC	0.31196
I	6	HiTEC	0.41132
T	2	Clear	0.80806
T	3	Clear	0.75626
T	6	Clear	0.83784
T	1	HiTEC	0.64212
T	4	HiTEC	0.56365
T	5	HiTEC	0.50427

Next we run a statistical model for AVG to determine if there are fuel effects and to determine if the fuel effects are car model specific or if there is a common fuel effect for all car models. [Note that the analysis presented in Section 3.2.1 did not allow for fuel effects to be car model specific.]

Table 3-5 summarizes these modeling results. The three rows of importance from Table 3-5 are those labeled "FUEL*MODEL".

TABLE 3-5. ANOVA ON AVERAGE EMISSIONS DETERMINED FROM FITTED QUADRATICS.

----- Average HC Emissions -----

Dependent Variable: AVG

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	1	0.01109930	0.01109930	22.09	0.0001
MODEL	7	0.94474224	0.13496318	268.55	0.0001
FUEL*MODEL	7	0.00152918	0.00021845	0.43	0.8728

----- Average CO Emissions -----

Dependent Variable: AVG

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	1	0.11923508	0.11923508	2.02	0.1654
MODEL	7	70.54738615	10.07819802	170.55	0.0001
FUEL*MODEL	7	0.92424015	0.13203431	2.23	0.0582

----- Average NO_x Emissions -----

Dependent Variable: AVG

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FUEL	1	0.11847392	0.11847392	24.80	0.0001
MODEL	7	1.56312876	0.22330411	46.75	0.0001
FUEL*MODEL	7	0.14916989	0.02130998	4.46	0.0016

The first "FUEL*MODEL" row indicates that average HC emissions depend on fuel in a common way for all car models. That is, there is no significant interaction between fuel type and car model because the P-value is 0.8728. The second "FUEL*MODEL" row indicates that the interaction between fuel and car model is marginally significant (i.e., P-value = 0.0582). However, to maintain consistency with our definition of statistical significance (i.e., 95 percent probability limit), we will not include a term to account for interaction for average CO emissions. The last "FUEL*MODEL" row of Table 3-5 clearly shows that average NO_x emissions are dependent on fuel in a car-model specific way (i.e., P-value = 0.0016).

We complete this part of the analysis by estimating the effects of switching from clear fuel to HiTEC 3000 in an overall or model specific way. We run the above indicated statistical models (i.e., we do not need an interaction term for average HC and CO emissions, but we do need an interaction term for average NO_x emissions).

Our modeling results are presented as SAS® computer outputs and are provided as Attachments 2B-9, 2B-10, and 2B-11. Attachment 2B-9 shows that switching from clear fuel to HiTEC 3000 results in an increase in average HC emissions of 0.020 gpvm. This result is based on intergration of quadratic functions over the 1,000 to 75,000 mileage interval.

Attachment 2B-10 shows that switching from clear fuel to HiTEC 3000 results in a decrease in average CO emissions of 0.139 gpvm. Lastly, Attachment 2B-11 shows the effect of switching fuels in both a model specific way and as an overall effect. Switching from clear fuel to HiTEC 3000 results in an overall

decrease in average NO_x emissions of 0.097 gpvm. Note that the effect on two car models is much larger than the overall effect. Switching from clear fuel to HiTEC 3000 results in a decrease of 0.317 gpvm for Model F cars and a decrease of 0.231 gpvm for Model T cars.

We complete our analysis of average differences in emissions between HiTEC 3000 and clear fuel by summarizing, in Table 3-6, the results obtained from ANOVA on average values and from integration of quadratic functions. Even though the degree of quadratic fit for the 75,000-mile data is not as good as for 50,000-mile data, the agreement between the quadratic results and the results based on simply averaging the emission measurements is excellent. This suggests that our estimates of differences in average emissions between clear fuel and HiTEC 3000 is quite robust.

TABLE 3-6. AVERAGE DIFFERENCES IN EMISSIONS (gpvm) FOR
75,000 MILE-DATA -- HiTEC 3000 VERSUS CLEAR FUEL.

Pollutant	ANOVA on Average Values	Integration of Quadratic Functions
HC	0.021 Higher	0.020 Higher
CO	0.155 Lower	0.139 Lower
NO_x	0.102 Lower	0.097 Lower

Figures 3-1, 3-2, and 3-3 show the quadratic trend for each pollutant, averaged across all clear-fuel cars and across all HiTEC 3000 cars. The graphs also show the data points upon which the quadratic curves are based.

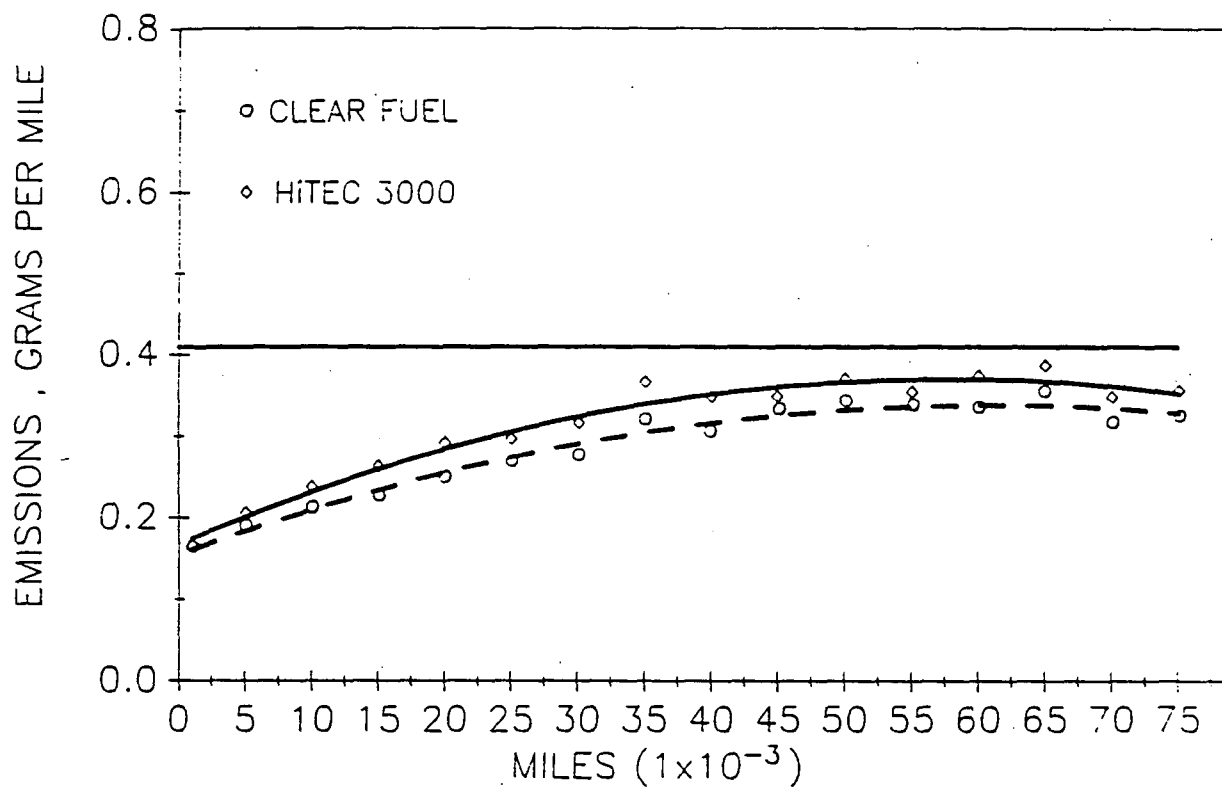


Figure 3-1. Quadratic trend of HC emissions averaged across all car models.

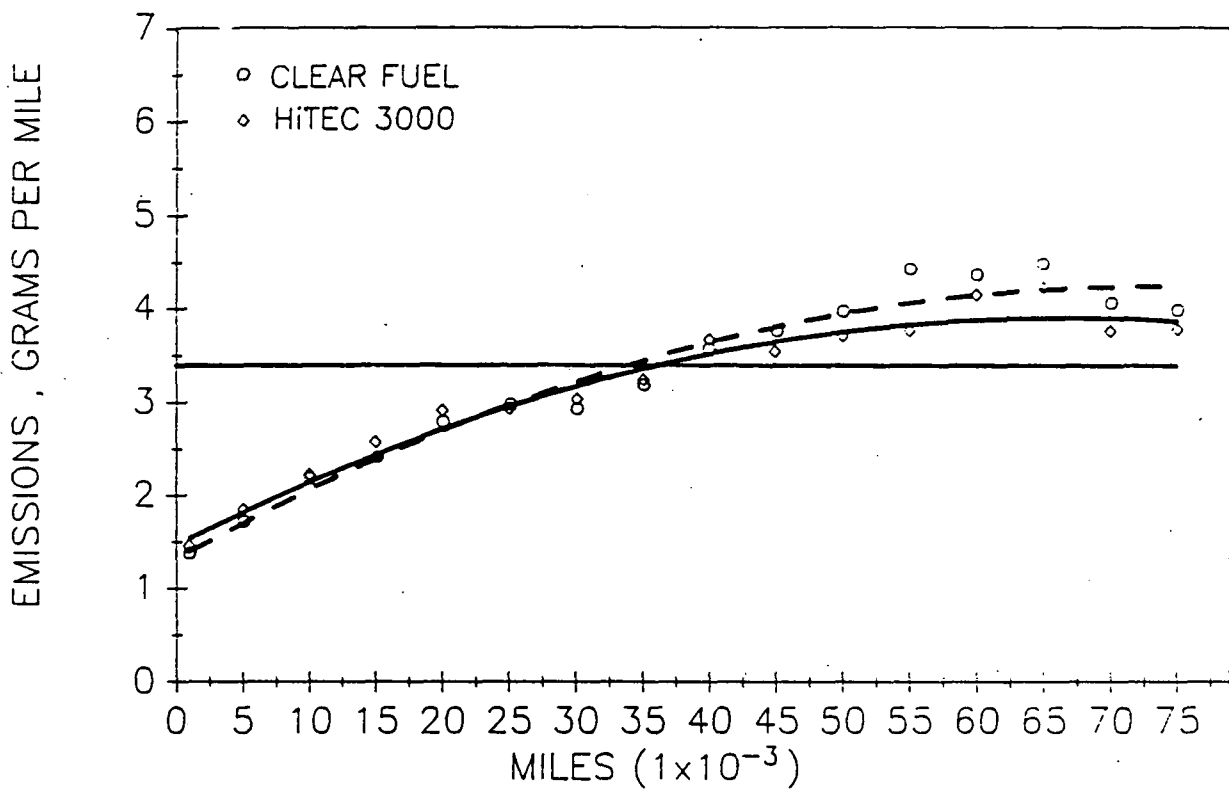


Figure 3-2. Quadratic trend of CO emissions averaged across all car models.

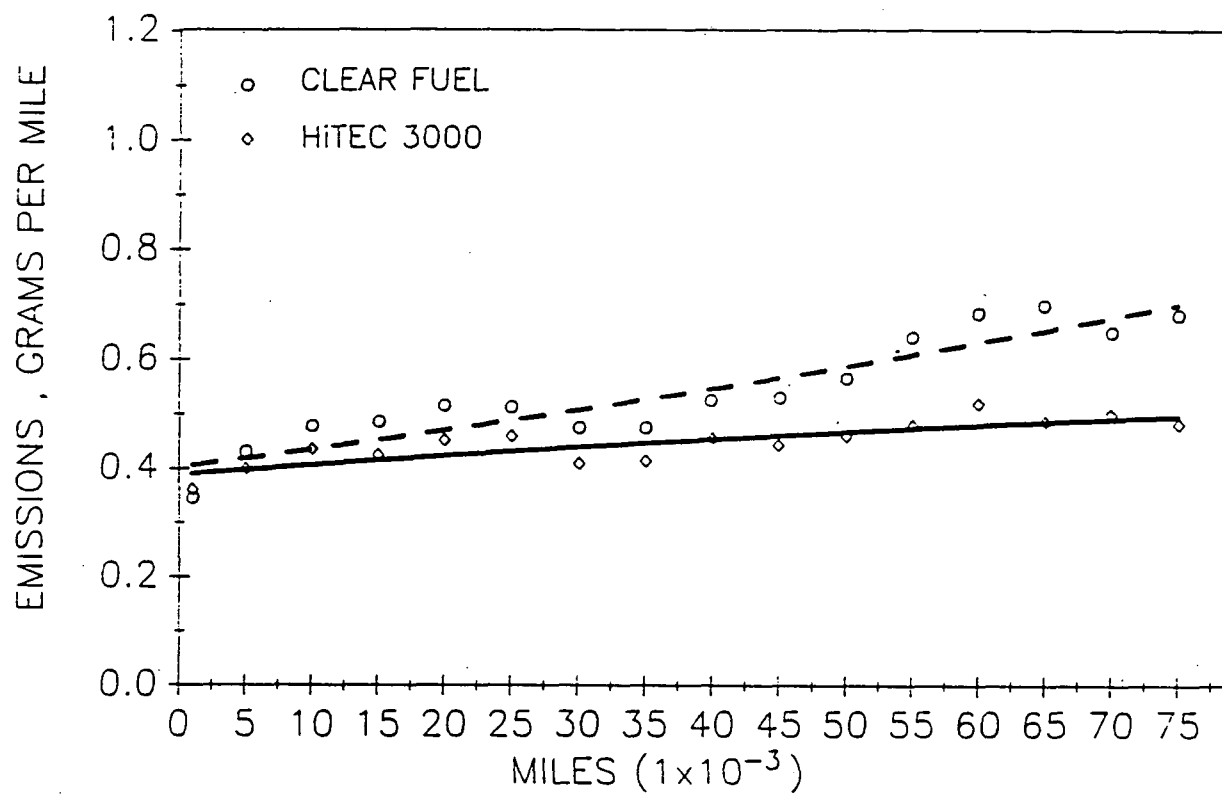


Figure 3-3. Quadratic trend of NO_x emissions averaged across all car models.

ATTACHMENTS

ATTACHMENT 2B-1. FITTED QUADRATICS FOR EACH CAR. AVG IS MEAN VALUE USING
INTEGRATION OF FITTED CURVE ANALYSIS OF HC CURVE --
50,000-MILE DATA.

Dependent Variable: AVG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.76693310	0.09586664	241.94	0.0001
Error	38	0.01505733	0.00039625		
Corrected Total	46	0.78199043			

R-Square	C.V.	Root MSE	AVG Mean
0.980745	7.076021	0.019906	0.28131515

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	0.3332262642 B	41.00	0.0001	0.00812656
MODEL C	-.1383102812 B	-12.03	0.0001	0.01149269
D	0.1655117518 B	13.72	0.0001	0.01206767
E	-.1535182253 B	-13.36	0.0001	0.01149269
F	0.1439047148 B	12.52	0.0001	0.01149269
G	-.1898710042 B	-16.52	0.0001	0.01149269
H	-.0640160584 B	-5.57	0.0001	0.01149269
I	-.1446385624 B	-12.59	0.0001	0.01149269
T	0.0000000000 B	.	.	.
HITEC_CLR	0.0113152295	3.89	0.0004	0.00290977

CONVERSION OF REGRESSION ESTIMATES TO DIFFERENCES.
DIFF IS PREDICTED DIFFERENCE BETWEEN FUELS (HITEC_CLEAR).

EST	DIFF
0.011315	0.022630

ATTACHMENT 2B-2. FITTED QUADRATICS FOR EACH CAR. AVG IS MEAN VALUE USING
INTEGRATION OF FITTED CURVE ANALYSIS OF CO CURVE --
50,000-MILE DATA.

Dependent Variable: AVG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	50.13920752	3.34261383	73.10	0.0001
Error	31	1.41743844	0.04572382		
Corrected Total	46	51.55664596			

R-Square	C.V.	Root MSE	AVG Mean
0.972507	7.454483	0.213831	2.86849239

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	3.777710547 B	43.27	0.0001	0.08729626
MODEL				
C	-1.221311136 B	-9.89	0.0001	0.12345555
D	-0.262948657 B	-2.01	0.0534	0.13094439
E	0.856516430 B	6.94	0.0001	0.12345555
F	-2.460786205 B	-19.93	0.0001	0.12345555
G	-1.947566055 B	-15.78	0.0001	0.12345555
H	-0.699753421 B	-5.67	0.0001	0.12345555
I	-1.433402417 B	-11.61	0.0001	0.12345555
T	0.000000000 B	.	.	.
HiTEC_CLR(Model)				
C	0.093112285	1.07	0.2944	0.08729626
D	0.019306710	0.20	0.8445	0.09760018
E	0.240318999	2.75	0.0098	0.08729626
F	-0.244346395	-2.80	0.0087	0.08729626
G	-0.011980560	-0.14	0.8917	0.08729626
H	-0.164323785	-1.88	0.0692	0.08729626
I	-0.010415515	-0.12	0.9058	0.08729626
T	0.067498123	0.77	0.4453	0.08729626

CONVERSION OF REGRESSION ESTIMATES TO DIFFERENCES.
DIFF IS PREDICTED DIFFERENCE BETWEEN FUELS (HiTEC_CLEAR).

MODEL	EST	DIFF
C	0.09311	0.18622
D	0.01931	0.03861
E	0.24032	0.48064
F	-0.24435	-0.48869
G	-0.01198	-0.02396
H	-0.16432	-0.32865
I	-0.01042	-0.02083
T	0.06750	0.13500

N Obs	Variable	Label	Mean
8	EST	regression coefficient = 1/2 effect	-0.0013538
	DIFF	effect of switch from clear to HiTEC	-0.0027075

ATTACHMENT 2B-3. FITTED QUADRATICS FOR EACH CAR. AVG IS MEAN VALUE USING
INTEGRATION OF FITTED CURVE ANALYSIS OF NO_x CURVE --
50,000-MILE DATA.

Dependent Variable: AVG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	1.20391182	0.08026079	21.37	0.0001
Error	31	0.11644668	0.00375634		
Corrected Total	46	1.32035850			

R-Square	C.V.	Root MSE	AVG Mean
0.911807	13.21268	0.061289	0.46386519

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	0.6446544501	25.76	0.0001	0.02502114
MODEL				
C	-.3318885855	-9.38	0.0001	0.03538523
D	-.1815533998	-4.84	0.0001	0.03753171
E	-.2938618918	-8.30	0.0001	0.03538523
F	0.1167176865	3.30	0.0024	0.03538523
G	-.2858262398	-8.08	0.0001	0.03538523
H	-.2258241385	-6.38	0.0001	0.03538523
I	-.2479011774	-7.01	0.0001	0.03538523
T	0.0000000000			
HiTEC_CLR(MODEL)				
C	-.0399361063	-1.60	0.1206	0.02502114
D	0.0221777507	0.79	0.4339	0.02797448
E	-.0109265829	-0.44	0.6654	0.02502114
F	-.0874501672	-3.50	0.0015	0.02502114
G	-.0045929742	-0.18	0.8556	0.02502114
H	0.0279954801	1.12	0.2718	0.02502114
I	-.0181719199	-0.73	0.4731	0.02502114
T	-.1239915217	-4.96	0.0001	0.02502114

MODEL	EST	DIFF
C	-0.03994	-0.07987
D	0.02218	0.04436
E	-0.01093	-0.02185
F	-0.08745	-0.17490
G	-0.00459	-0.00919
H	0.02800	0.05599
I	-0.01817	-0.03634
T	-0.12399	-0.24798

N Obs	Variable	Label	Mean
8	EST	regression coefficient = 1/2 effect	-0.0293620
	DIFF	effect of switch from clear to HiTEC	-0.0587240

ATTACHMENT 2B-4. EXCEEDANCE MILEAGE ANALYSIS FOR HC EMISSIONS.

Dependent Variable: CROSS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2780.434490	926.811497	50.55	0.0001
Error	13	238.334496	18.333423		
Corrected Total	16	3018.768986			

R-Square	C.V.	Root MSE	CROSS Mean
0.921049	16.65194	4.281755	25.7132457

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	2	2736.800669	1368.400334	74.64	0.0001
HiTEC_CLR	1	43.633821	43.633821	2.38	0.1469

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	42.81153242 B	24.49	0.0001	1.74801901
MODEL D	-27.78340153 B	-10.68	0.0001	2.60113553
F	-25.02371134 B	-10.12	0.0001	2.47207219
T	0.00000000 B	.	.	.
HiTEC_CLR	-1.61159898	-1.54	0.1469	1.04464117

ATTACHMENT 2B-5. EXCEEDANCE MILEAGE ANALYSIS FOR CO EMISSIONS.

Dependent Variable: CROSS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	2411.278014	301.409752	10.01	0.0001
Error	16	481.726008	30.107876		
Corrected Total	24	2893.004022			

R-Square	C.V.	Root MSE	CROSS Mean
0.833486	25.53376	5.487064	21.4894517

Source	DF	Type I SS	Mean Square	F Value	Pr > F
MODEL	4	2142.513569	535.628392	17.79	0.0001
HiTEC-CLR(MODEL)	4	268.764445	67.191111	2.23	0.1114

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	21.11142014 B	9.42	0.0001	2.24008465
MODEL C	17.52541010 B	3.91	0.0012	4.48016931
D	3.03109281 B	0.90	0.3804	3.36012698
E	-13.97757222 B	-4.41	0.0004	3.16795810
H	7.26146086 B	2.29	0.0358	3.16795810
T	0.00000000 B	.	.	.
HiTEC_CLR(MODEL) C	0.00000000 B	.	.	.
D	-0.45882606 B	-0.18	0.8569	2.50449078
E	-4.61489631 B	-2.06	0.0560	2.24008465
H	4.42531013 B	1.98	0.0657	2.24008465
T	-1.93520524 B	-0.86	0.4004	2.24008465

ATTACHMENT 2B-6. ANOVA ON CAR AVERAGES -- AVERAGE HC EMISSIONS.

Dependent Variable: MNHC

Parameter		Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT		0.3658611111 B	41.04	0.0001	0.00891434
MODEL	C	-.1654300109 B	-13.12	0.0001	0.01260678
	D	0.2075991884 B	15.68	0.0001	0.01323751
	E	-.1627434641 B	-12.91	0.0001	0.01260678
	F	0.1658676471 B	13.16	0.0001	0.01260678
	G	-.2135811547 B	-16.94	0.0001	0.01260678
	H	-.0382854031 B	-3.04	0.0043	0.01260678
	I	-.1741972699 B	-13.82	0.0001	0.01260678
	T	0.0000000000 B	.	.	.
HITEC_CLR		0.0102573259	3.21	0.0027	0.00319185

Changing regression coefficients to effects
Dependent Variable: MNHC

EST	DIFF
0.010257	0.020515

ATTACHMENT 2B-7. ANOVA ON CAR AVERAGES -- AVERAGE CO EMISSIONS.

Dependent Variable: MNCO

Parameter		Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT		4.840699074 B	49.17	0.0001	0.09844390
MODEL	C	-2.191120098 B	-15.74	0.0001	0.13922069
	D	-0.498539760 B	-3.38	0.0020	0.14766584
	E	0.536423475 B	3.85	0.0005	0.13922069
	F	-3.187963126 B	-22.90	0.0001	0.13922069
	G	-2.806224673 B	-20.16	0.0001	0.13922069
	H	-1.136683007 B	-8.16	0.0001	0.13922069
	I	-2.397905399 B	-17.22	0.0001	0.13922069
	T	0.000000000 B	.	.	.
HiTEC CLR(MODEL)	C	0.107108388	1.09	0.2850	0.09844390
	D	-0.096884804	-0.88	0.3855	0.11006362
	E	0.032897059	0.33	0.7405	0.09844390
	F	-0.385115686	-3.91	0.0005	0.09844390
	G	0.040339325	0.41	0.6848	0.09844390
	H	-0.133115741	-1.35	0.1861	0.09844390
	I	-0.072910573	-0.74	0.4645	0.09844390
	T	-0.110819444	-1.13	0.2689	0.09844390

Changing regression coefficients to effects
Dependent Variable: MNCO

EST	DIFF
0.10711	0.21422
-0.09688	-0.19377
0.03290	0.06579
-0.38512	-0.77023
0.04034	0.08068
-0.13312	-0.26623
-0.07291	-0.14582
-0.11082	-0.22164

N Obs	Variable	Label	Mean
8	EST	regression coefficient = 1/2 effect	-0.0773127
	DIFF	effect of switch from clear to HiTEC	-0.1546254

ATTACHMENT 2B-8. ANOVA ON CAR AVERAGES -- AVERAGE NO_x EMISSIONS.

Dependent Variable: MNNOX

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	0.6954027778 B	23.24	0.0001	0.02992486
MODEL				
C	-.3227766885 B	-7.63	0.0001	0.04232014
D	-.2134003268 B	-4.75	0.0001	0.04488729
E	-.2956576797 B	-6.99	0.0001	0.04232014
F	0.2140354575 B	5.06	0.0001	0.04232014
G	-.3132843137 B	-7.40	0.0001	0.04232014
H	-.2961909041 B	-7.00	0.0001	0.04232014
I	-.2791410335 B	-6.60	0.0001	0.04232014
T	0.0000000000 B	.	.	.
HiTEC_CLR (MODEL)				
C	-.0673837146	-2.25	0.0316	0.02992486
D	0.0119289216	0.36	0.7238	0.03345701
E	-.0134803922	-0.45	0.6555	0.02992486
F	-.1665964052	-5.57	0.0001	0.02992486
G	-.0107949346	-0.36	0.7207	0.02992486
H	-.0070904139	-0.24	0.8143	0.02992486
I	-.0444550313	-1.49	0.1475	0.02992486
T	-.1082546296	-3.62	0.0010	0.02992486

Changing regression coefficients to effects
Dependent Variable: MNNOX

EST	DIFF
-0.06738	-0.13477
0.01193	0.02386
-0.01348	-0.02696
-0.16660	-0.33319
-0.01079	-0.02159
-0.00709	-0.01418
-0.04446	-0.08891
-0.10825	-0.21651

N Obs	Variable	Label	Mean
8	EST	regression coefficient = 1/2 effect	-0.0507658
	DIFF	effect of switch from clear to HiTEC	-0.1015316

ATTACHMENT 2B-9. FITTED QUADRATICS FOR EACH CAR. AVG IS MEAN VALUE USING
INTEGRATION OF FITTED CURVE ANALYSIS OF HC CURVE -- 75,000-
MILE DATA.

Dependent Variable: AVG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	0.95584154	0.11948019	265.38	0.0001
Error	38	0.01710836	0.00045022		
Corrected Total	46	0.97294990			

R-Square	C.V.	Root MSE	AVG Mean
0.982416	6.943763	0.021218	0.30557477

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	0.3599930321 B	41.56	0.0001	0.00866237
MODEL C	-.1599078072 B	-13.05	0.0001	0.01225044
D	0.1952818745 B	15.18	0.0001	0.01286334
E	-.1610736674 B	-13.15	0.0001	0.01225044
F	0.1530623288 B	12.49	0.0001	0.01225044
G	-.2094577741 B	-17.10	0.0001	0.01225044
H	-.0445541013 B	-3.64	0.0008	0.01225044
I	-.1687554718 B	-13.78	0.0001	0.01225044
T	0.0000000000 B	.	.	.
HITEC_CLR	0.0100510966 B	3.24	0.0025	0.00310163

CONVERSION OF REGRESSION ESTIMATES TO DIFFERENCES.
DIFF IS PREDICTED DIFFERENCE BETWEEN FUELS (HITEC_CLEAR).

EST	DIFF
0.010051	0.020102

ATTACHMENT 2B-10. FITTED QUADRATICS FOR EACH CAR. AVG IS MEAN VALUE USING
INTEGRATION OF FITTED CURVE ANALYSIS OF CO CURVE -- 75,000
MILE DATA.

Dependent Variable: AVG (almost inappropriate according to interaction test)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	70.66662124	8.83332765	121.79	0.0001
Error	38	2.75609131	0.07252872		
Corrected Total	46	73.42271254			

R-Square	C.V.	Root MSE	AVG Mean
0.962463	8.266617	0.269312	3.25782084

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	4.590870181 B	41.76	0.0001	0.10994599
MODEL C	-1.950348512 B	-12.54	0.0001	0.15548710
D	-0.426624014 B	-2.61	0.0128	0.16326621
E	0.624633046 B	4.02	0.0003	0.15548710
F	-2.982425696 B	-19.18	0.0001	0.15548710
G	-2.587954545 B	-16.64	0.0001	0.15548710
H	-1.015570507 B	-6.53	0.0001	0.15548710
I	-2.163426611 B	-13.91	0.0001	0.15548710
T	0.000000000 B	.	.	.
HITEC_CLR	-0.069642058	-1.77	0.0849	0.03936698

CONVERSION OF REGRESSION ESTIMATES TO DIFFERENCES.
DIFF IS PREDICTED DIFFERENCE BETWEEN FUELS (HITEC_CLEAR).

EST	DIFF
-0.069642	-0.13928

ATTACHMENT 2B-11. FITTED QUADRATICS FOR EACH CAR. AVG IS MEAN VALUE USING INTEGRATION OF FITTED CURVE ANALYSIS OF NOX CURVE -- 75,000-MILE DATA.

Dependent Variable: AVG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	15	1.83077257	0.12205150	25.55	0.0001
Error	31	0.14808528	0.00477694		
Corrected Total	46	1.97885785			

R-Square	C.V.	Root MSE	AVG Mean
0.925166	13.74265	0.069115	0.50292677

Parameter	Estimate	T for H0: Parameter=0	Pr > T	Std Error of Estimate
INTERCEPT	0.6853675779 B	24.29	0.0001	0.02821626
MODEL C	-.3225909625 B	-8.08	0.0001	0.03990382
D	-.2048811115 B	-4.84	0.0001	0.04232439
E	-.2953325969 B	-7.40	0.0001	0.03990382
F	0.2187898343 B	5.48	0.0001	0.03990382
G	-.3100362825 B	-7.77	0.0001	0.03990382
H	-.2825295261 B	-7.08	0.0001	0.03990382
I	-.2690307482 B	-6.74	0.0001	0.03990382
T	0.0000000000 B	.	.	.
HITEC_CLR (MODEL) C	-.0616610184	-2.19	0.0365	0.02821626
D	0.0140692912	0.45	0.6587	0.03154674
E	-.0152624831	-0.54	0.5924	0.02821626
F	-.1586735180	-5.62	0.0001	0.02821626
G	-.0103452733	-0.37	0.7164	0.02821626
H	-.0002605160	-0.01	0.9927	0.02821626
I	-.0396260755	-1.40	0.1701	0.02821626
T	-.1153529630	-4.09	0.0003	0.02821626

CONVERSION OF REGRESSION ESTIMATES TO DIFFERENCES.
DIFF IS PREDICTED DIFFERENCE BETWEEN FUELS (HITEC_CLEAR).

EST	DIFF
-0.06166	-0.12332
0.01407	0.02814
-0.01526	-0.03052
-0.15867	-0.31735
-0.01035	-0.02069
-0.00026	-0.00052
-0.03963	-0.07925
-0.11535	-0.23071

N Obs	Variable Label	Mean
8	EST REGRESSION ESTIMATE = 1/2 DIFFERENCE	-0.0483891
	DIFF ESTIMATED DIFFERENCE HITEC_CLEAR	-0.0967781

Appendix 2C

APPENDIX 2C

INSTANTANEOUS EFFECTS ANALYSIS

Summary

One of the criteria that the Administrator of the Environmental Protection Agency uses to evaluate the environmental effect of a potential gasoline additive is its instantaneous effect on the automobile's emission system. That is, does the additive cause a significant increase in pollutants emitted from the tailpipe as soon as the additive is introduced into the gasoline. HiTEC® 3000 Performance Additive ("HiTEC 3000") was tested for a possible instantaneous effect on the emission systems on automobiles with similar engine configurations to those in Ethyl Corporation's ("Ethyl") 48-car test fleet.

To determine whether the HiTEC 3000 additive contributes to an instantaneous increase in automotive emissions, Ethyl tested nine rental automobiles, with engine configurations similar to the eight models in its 48-car test fleet, for HC, CO, and NOx tailpipe emissions. Ethyl conducted these tests with a clear test fuel first and then with the same test fuel treated with the HiTEC 3000 additive. The test results indicated that there were no statistically significant differences between the emission levels of the two fuels.

Discussion

The Environmental Protection Agency requires that waiver applicants for additives in unleaded gasoline provide evidence that the additive does not cause a negative instantaneous effect on automotive exhaust emissions. In order to check for instantaneous effects, emission tests are conducted on a particular automobile with a control fuel and then with the waiver fuel using the same automobile.

Test Procedure - Ethyl leased nine automobiles that had the same engine configurations as the eight-engine model families in Ethyl's 48-car test fleet. The intention was to test only eight automobiles, one from each engine model in the test fleet. Ethyl actually tested nine automobiles because the first "D" model leased by Ethyl gave inconsistent test results for HC and NOx. A second "D" model was leased and emission ratings were obtained; however, the inclusion of the second "D" model in the data set did not change the outcome of the three statistical tests for instantaneous effects. A description of the automobiles used for the instantaneous emissions testing is given in Attachment 2C-1. The catalyst number for the second "D" model was not documented when Ethyl leased the vehicle so it does not appear in Attachment 2C-1.

-2-

Emission tests were performed according to FTP-75 guidelines. Each automobile was tested in triplicate with Howell EEE gasoline followed by triplicate ratings with Howell EEE gasoline containing 0.03125 gm Mn as the HiTEC 3000 additive. The automobiles were leased in Detroit, Michigan and testing was conducted by ECS Laboratories. The emission test data for HC, CO, and NOx for both fuels in the nine vehicles are shown in Attachment 2C-2.

Data Analysis - In prior waiver requests, the Environmental Protection Agency has used three different statistical procedures to check for instantaneous emission effects. These test procedures are the (1) paired difference test, (2) sign of difference test and (3) deteriorated emissions test. A description of the tests and results of the data analysis for the HiTEC 3000 additive follow.

(1) Paired Difference Test - For each vehicle, compute the mean difference between the control fuel and waiver fuel emissions for each pollutant. Then calculate a 90% confidence interval about the estimate for the true mean difference. This interval is expected to include the theoretical increase (or decrease) in emissions due to the additive. The instantaneous effect is regarded as adverse if the entire interval exceeds zero or if the upper bound exceeds 10% of the standard.

The statistical method used is an analysis of differences in average performance between two variables assuming the differences come from the same normal distribution. In this case, the two variables are the tailpipe emissions obtained with Howell EEE gasoline and with Howell EEE gasoline containing 0.03125 gm Mn as the HiTEC 3000 additive. The student's "t" statistic is used to calculate 90% confidence intervals. The variance " s_d^2 " used in the analysis is calculated using the differences in average performance between the two variables.

The 90% confidence interval about the mean difference is obtained by calculating the variable:

$$u = t(0.95, df) \times s_d \times \text{SQRT}(n)$$

Where:

$t(0.95, df)$ = student's "t" value at 0.05 significance level
and n-1 degrees of freedom

SQRT = Square root

n = Number of observations

-3-

The lower and upper limits of the 90% confidence interval is represented by the values:

$$\text{XBAR}_d - u \quad \text{and} \quad \text{XBAR}_d + u$$

Where:

XBAR_d = Mean of the difference between the HiTEC 3000 additive emissions and Howell EEE emissions

The results of the paired difference statistical calculations for the three emission types are given in Attachment 2C-3. The results indicate that the HiTEC 3000 additive does not have an adverse instantaneous effect on automotive tailpipe emissions. The average overall effect for HC and NOx is essentially zero while CO emissions show a favorable (decrease) effect for the HiTEC 3000 additive. The 90 percent confidence intervals for the three emission types include zero but none of the upper limits of the intervals exceed 10 percent of the Federal emission standards.

(2) Sign of Difference Test - This test assigns a "+" if the mean difference between the HiTEC 3000 additive emissions and Howell EEE emissions is positive and concurrently a "-" if the difference is negative. The number of pluses is counted and if the percentage is significantly higher than 50% of total observations, then the HiTEC 3000 additive would be seen to contribute to an adverse instantaneous effect on tailpipe emissions. The method used is a standard binomial test where the probability of a "+" = the probability of a "-" = 0.5.

The HiTEC 3000 additive does not cause an instantaneous effect on automotive emissions when the sign of difference statistical test is applied to the data. The maximum number of positive effects for the HiTEC 3000 additive in the nine automobiles was 4 which is even less than 50% of the nine observations. The minimum number of positive effects necessary to be statistically significant at the 90% confidence level in 9 trials is 7. The data are shown in Attachment 2C-4.

(3) Deteriorated Emissions Test - In this test the mean difference between the HiTEC 3000 additive and Howell EEE for each vehicle is added to the 50,000 mile certification value applicable to each vehicle to get a prediction of the waiver fuel emissions at 50,000 miles. The HiTEC 3000 additive is regarded as causing the vehicle to fail the emission standard if the predicted value exceeds the standard. The additive fails this test if the predicted number of failing vehicles is statistically significant.

-4-

The HiTEC 3000 additive does not cause an adverse instantaneous effect on automotive emissions when analyzed by the deteriorated emissions test. None of the mean effects exceed the federal emission standards when added to the 50,000 mile certification value applicable to each specific vehicle. The data for each vehicle/pollutant combination is shown in Attachment 2C-5. The 50,000 mile certification values for each vehicle were obtained from the Environmental Protection Agency.

Conclusion

Ethyl has done emission testing under Environmental Protection Agency guidelines to determine if the HiTEC 3000 additive causes adverse instantaneous effects to automotive emissions. Statistical analysis of the data, using three different testing procedures, indicates that the HiTEC 3000 additive does not cause adverse instantaneous effects to automotive tailpipe emissions.

Attachment 2C-1

AUTOMOBILES - INSTANTANEOUS EFFECTS

MODEL	C
V.I.N.	1G1JC5116JJ230682
ENGINE	2.0L J1G2.0V5XAG7
CATALYST	BPEGR/ORC
MODEL	G
V.I.N.	1G1AW51R7J6189377
ENGINE	2.5L J1G2.5V5TPG4 JAO-1C
CATALYST	BPEGR/ORC
MODEL	H
V.I.N.	1G2WJ14WXJF254703
ENGINE	2.8L J1G2.8V8XRZ8 JBO-1K
CATALYST	EGR/ORC
MODEL	I
V.I.N.	1G4HP54C0KH409549
ENGINE	3.8L K2G3.8V8XEB1 KBO-2O
CATALYST	EGR/ORC
MODEL	E
V.I.N.	1FAPP9592KW270441
ENGINE	1.9L KFM1.9V5FFF6
CATALYST	E9AE-9C485-8DV
MODEL	T
V.I.N.	1FABP52U9KG213904
ENGINE	3.0L SHM KFM3.0V5FEG0
CATALYST	E9AE-9C485-BAB
MODEL	F
V.I.N.	2FABP74FKX176846
ENGINE	5.0L 9HM KFM5.0V5HBF4
CATALYST	E9AE-9C485-BAZ
MODEL	D
V.I.N.	1B3B956326D216682
ENGINE	KCR3.0V5FBL5
CATALYST	4300655
MODEL	D
V.I.N.	1B30BU5630JD121070
ENGINE	KCR3.0V5FBL5
CATALYST	NOT AVAILABLE

Attachment 2C-2

INSTANTANEOUS EFFECTS DATA*All Models*

<u>CAR MODEL</u>	<u>HC, GM/MILE</u>		<u>CO, GM/MILE</u>		<u>NOX, GM/MILE</u>	
	<u>Clear</u>	<u>H3000</u>	<u>Clear</u>	<u>H3000</u>	<u>Clear</u>	<u>H3000</u>
C	0.175	0.162	2.847	2.245	0.409	0.348
	0.155	0.166	2.193	2.413	0.281	0.343
	0.158	0.168	2.125	2.259	0.335	0.402
G	0.173	0.150	2.188	1.842	0.472	0.457
	0.177	0.158	2.683	1.775	0.514	0.446
	0.147	0.157	1.682	1.880	0.450	0.473
H	0.418	0.459	2.976	2.555	0.316	0.386
	0.396	0.442	2.881	2.337	0.310	0.356
	0.394	0.378	2.812	2.280	0.301	0.380
I	0.205	0.181	2.142	2.378	0.325	0.334
	0.190	0.176	2.180	1.971	0.356	0.321
	0.172	0.179	2.245	2.142	0.376	0.328
E	0.151	0.147	3.558	3.591	0.611	0.564
	0.159	0.151	3.984	3.859	0.625	0.556
	0.151	0.157	3.787	3.910	0.574	0.571
T	0.261	0.258	3.719	3.178	0.647	0.573
	0.303	0.241	3.323	2.867	0.593	0.655
	0.260	0.242	3.127	2.901	0.669	0.643
F	0.286	0.264	0.894	0.805	0.737	0.761
	0.303	0.273	1.079	1.065	0.704	0.739
	0.282	0.295	0.828	1.121	0.758	0.766
D	0.573	0.620	2.336	2.156	0.353	0.434
	0.553	0.606	1.822	2.169	0.414	0.504
	0.700	0.709	2.186	2.485	0.430	0.420
D	0.465	0.474	2.937	3.203	0.419	0.337
	0.513	0.456	3.529	2.975	0.393	0.355
	0.469	0.503	3.058	3.426	0.416	0.341

Attachment 2C-3

INSTANTANEOUS EFFECTS SUMMARY*Paired Difference Test*

<u>CAR MODEL</u>	<u>Mileage</u>	<u>Mean Difference, HiTEC 3000 - Howell EEE (gm/mi)</u>		
		<u>HC</u>	<u>CO</u>	<u>NOx</u>
C	24588	0.003	-0.083	0.023
G	30539	-0.011	-0.352	-0.020
H	18597	0.024	-0.499	0.065
I	21343	-0.010	-0.025	-0.025
E	11667	-0.002	0.010	-0.040
T	10513	-0.028	-0.408	-0.013
F	12959	-0.013	0.063	0.022
D	33936	0.036	0.155	0.054
D	30217	-0.005	0.027	-0.065
Average Difference		-0.001	-0.123	0.000
<u>90% Conf. Interval</u>				
Lower		-0.013	-0.269	-0.027
Upper		0.012	0.022	0.027
Upper Limit Exceeds 10% of Standard?		No	No	No

INSTANTANEOUS EFFECTS SUMMARY

Sign of Difference Test

<u>CAR MODEL</u>	<u>HiTEC 3000 Effect</u>		
	<u>HC</u>	<u>CO</u>	<u>NOx</u>
C	+	-	+
G	-	-	-
H	+	-	+
I	-	-	-
E	-	+	-
T	-	-	-
F	-	+	+
D	+	+	+
D	-	+	-

P = Number of pluses 3 4 4

Number of P's necessary in 9 trials to be 90 percent confident that HiTEC 3000 has an adverse effect is "7". Therefore, the hypothesis that HiTEC 3000 has an adverse effect is rejected.